BONUS! Guide to the Night Sky 2015

KEPLER SPACECRAFT'S NEW LEASE ON LIFE p. 44

WHERE ARE THE **WOMEN** IN AMATEUR ASTRONOMY? p. 60

JANUARY 2015

Astronomy®

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ANNUAL SPECIAL

Top 10 space stories of the year

- The universe awash in cosmic dust
- Rosetta encounters a comet
- Plate tectonics on Europa
- Intermediate-mass black holes
- Below surface ocean on Enceladus

AND MORE p. 24

The Atacama Large Millimeter/submillimeter Array revealed a large mass of dust concentrated at the core of Supernova 1987A, as illustrated here.

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FEATURES

JANUARY 2015
VOL. 43, NO.1

ALEXANDRA ANGELICH (NRAO/AUI/NSF)

ON THE COVER

In 2014, scientists discovered that supernovae, like the one illustrated here, produce cosmic dust.

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

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FROM THE **EDITOR**

BY DAVID J. EICHER

2014 stories that made an impact

Each year, the editors of *Astronomy* are excited to bring you a new rendition of our "top 10 space stories" feature, this year once again written by Liz Kruesi, our contributing editor. The past year has been a dynamic one in astronomy, astrophysics, and cosmology, as this big story proves (p. 24).

The discoveries and realizations this year were as exciting as ever. We have two important studies about cosmic dust in the solar system and the Milky Way that clarify how dust forms — from the explosions of supernovae scattered throughout the galaxy. Astronomers also measured the distance to some remote galaxies at high precision, helping further nail down the cosmic distance scale.

Closer to home, planetary scientists discovered a subsurface ocean on Enceladus, the watery moon of Saturn, which feeds the world's well-documented geysers of slushy, icy water. Scientists believe the moon harbors about as much water underneath the crust as is contained in Lake Superior.

Astronomers also have detected the telltale signature of water in the atmospheres of two other small bodies of the solar system — Jupiter's moon Europa and the dwarf planet Ceres.

And that wasn't all scientists discovered at Europa in 2014. For years, astronomers have observed cracks and ridges on the jovian moon, some of which end abruptly. To planetary scientists, this means some of the cracks and ridges are being subducted — pulled back down under the planet's icy shell. This geological activity on Europa was surprising and suggests plate tectonics is at work, pending a future mission to confirm the finding.

Furthermore, the cosmology world was shocked into excitement early this year when scientists using an instrument called BICEP2, located at the South Pole, announced the detection of the faint signature of the ripples of space-time coming from the universe's first second. That finding proved to be somewhat controversial, however, and astronomers now have backed off on that apparently exciting result, awaiting more data.

On a staff note, please join me in welcoming Eric Betz as *Astronomy*'s newest associate editor. Betz joins us from the *Arizona Daily Sun* in Flagstaff, where he covered science and the environment in the world's first international dark-sky city.

Betz reported on everything from dinosaur digs to the logging industry, from endangered species to the Discovery Channel Telescope, the Grand Canyon, and anything in between. But astronomy is his true passion.

The Santa Cruz, California, native learned to love the night sky while wandering rugged beaches and coastal redwood forests as a young man. He ultimately moved to the high deserts of the Southwest to pursue a career in astronomy.

Eric Betz. JIM FORBES

There, Betz spent eight years mesmerized by the dark skies of the Colorado Plateau. One highlight: Staring at the stars from below the North Rim of Grand Canyon National Park.

Yours truly,

David J. Eicher
Editor

Astronomy

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QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES>>

TRENDING TO THE TOP

GUSTS AGLOW
A telescope array in Chile spotted winds around a T Tauri star — an infant Sun with the rock and gas to build planets. It could explain their odd glow.

SPACE SLOWDOWN
Delays caused by diffuse dust clouds may explain why a few gamma-ray bursts, the most intense explosions known, lasted five hours, not seconds.

LUNAR LEAP
NASA tests show future moonwalkers will pace faster than thought. Researchers say Apollo suits made crews walk funny, not just gravity.

SNAPSHOT

The first stargazers

Seven million years ago, the first bipedals must have looked skyward.

Some 7 million years ago, a group of creatures made their way across the plains of central Africa. Resembling a collection of savannah baboons, the 30 or so beings shuffled along as dusk began to fall over a clearing in what we now call Chad. Adult females and flocks of offspring made up the nucleus of this foray, with a few mature males following up and looking for mating opportunities. As darkness began to fall, the group approached a cave that held a common shelter, and light from the Moon blazed down onto what now appeared like black, slumped forms — dirty, disheveled, hairy, and marked by spots of blood from the day's successful hunt.

These earliest human beings, perhaps *Sahelanthropus*, were the first bipedals and walked more or less upright. They stand among the earliest creatures known from around the time of the human/chimpanzee divergence, when our ancestors began to make their own lineage that would one day lead to *Homo sapiens*. As these creatures, primitive by today's standards, shambled back to their nightly caves, they no doubt occasionally looked skyward at the Moon and the stars. Perhaps they wondered what those lights in the sky meant. Somewhere around this time, some kind of creatures like *Sahelanthropus* became the first early human ancestors to ponder what space above meant to them. — **David J. Eicher**

Sahelanthropus tchadensis, present in Chad some 7 million years ago, may have been the first high-thinking bipedal on Earth.

DIDIER DESCOUENS/CREATIVE COMMONS (SKULL); NOAO/AURA/NSF (GUSTS AGLOW); PHIL EVANS/UNIVERSITY OF LEICESTER (SPACE SLOWDOWN); NASA (LUNAR LEAP)

BREAK
THROUGH

Distant cousins

In space, neighbors are not always what they seem. Take this pair of star-forming regions in the southern constellation Carina the Keel. Both glow with a reddish hue as hot young stars in their centers pump out ultraviolet radiation that excites surrounding clouds of hydrogen gas. But emission nebula NGC 3576 (top) lies only 9,000 light-years from Earth, while star cluster NGC 3603 and its gaseous cocoon (bottom) reside 20,000 light-years away. NGC 3603 has the highest concentration of heavyweight stars known in the Milky Way, and its hydrogen envelope is our galaxy's most massive.

ESO/G. BECCARI

STRANGE**UNIVERSE**

BY BOB BERMAN

Crazy inferior worlds

Explore the oddities of a fabulous conjunction.

The inferior planets, Venus and Mercury, will be anything but the second week of January.

Venus had a crummy 2014, but it's now returning with a vengeance. Look west 40 minutes after sunset for two "stars" near the horizon. The brighter is Venus, on the left. The other is Mercury. From the 8th to the 13th, they'll hover strikingly close to each other.

They're the only planets with no moons. The only ones that barely spin — needing months to rotate. (Every other planet's day is less than 25 hours.) The only planets that can appear as crescents. The only ones with high densities similar to our world. These are intriguing resemblances.

But here's what's weird. In most other areas, they're not merely dissimilar, but oddly *opposite*.

Venus' surface sits under more air pressure than any other terrestrial body in the solar system. Its surface matches what you'd experience 3,000 feet (1,000 meters) below sea level — enough to crush a submarine's hull. It's like a defective pressure cooker about to explode. By contrast, Mercury is the only planet with virtually no air at all.

Venus is the shiniest planet by far. By contrast, Mercury is the *least* reflective. It's as dark as an asphalt parking lot. Venus has the most circular path around the Sun of any planet. This gives it a steady cruise-control orbital velocity of 22 miles (35 kilometers) per second. It doesn't vary. By contrast, Mercury has the most oval, squashed orbit, so it dramatically slows down and speeds up like a drunk driver. Someone on its surface would sometimes see the enormous Sun rise, then drop below the horizon, then rise a second time.

Next consider axial tilt. Venus' is off the charts at 177°. That world is actually upside down. By contrast, Mercury has no tilt at all. Not even one degree. Not even half a degree. If you want to be picky, it's 1/30°. The plane of its equator is its path around the Sun.

Mercury makes three spins while circling the Sun twice, the only planet with a resonance between its day and year. As a consequence, the period from one sunrise to the next is exactly two Mercury years. Nearly six months. Crazy slow. The Sun crosses as much of Mercury's sky in a month as it traverses ours in two hours. During that long, grueling day, the Sun grows 1.5 times larger and more than doubles its intensity as the planet sizzles through its brutal perihelion. Then the Sun thankfully shrinks again.

IN MOST AREAS, MERCURY AND VENUS ARE NOT MERELY DISSIMILAR, BUT ODDLY *OPPOSITE*.

Mercury's bizarre 3:2 day-to-year ratio means we telescopically observe the same Mercury features *every other time* it circles the Sun. No wonder we believed until the 1960s that its spin rate matched its orbit, the way our Moon's does. Observers seemed to keep sketching the same dusky markings. Turned out, they saw repetitions only half the time. They'd shrugged and simply tossed out the ones that didn't fit. Human nature.

Could the contrasts of those worlds get any odder?

Actually, yes. Venus has a nonexistent day/night temperature range. Its ultra-thick air keeps both its day and night hemispheres baking at an even thermostat setting of 870° F (465° C). You don't need an oven there. The Cytherean gourmet cookbook calls for just two seconds for pot roast. Same for rice, since Venus' high pressure only lets water boil above 500° F (250° C). But Mercury, always the contrarian, has the greatest day/night range of any object in the solar system. There, the mercury (ha!) plunges some 1,000° F (600° C) after sunset. Its rocks go from hot enough to melt lead to cold enough to liquefy oxygen.

The oddest observational contrast between these two worlds? Venus gets brightest when it's on our side of the Sun and nearly at its closest to us. But Mercury is brightest when it's about as far away as it can get.

Right now, both have recently emerged from behind the Sun, on the far side of their orbits. Thus, Mercury is now nearly at its brightest while Venus is dimmest. (Of course, even a "dim" Venus always outshines Mercury.) Venus alters its brightness threefold during its full synodic cycle. But Mercury varies its brilliance by an astonishing factor of *1,000*, more than any other planet. This year its magnitude changes from –2.2 to 5.3, equaling the brightness difference between Vega and Neptune.

The second week of January finds Mercury in the bright section of its orbit at magnitude –0.8 and easy to spot close to Venus. Their conjunction, a bit low in the fading twilight, requires an unobstructed horizon.

They're both fascinating and bizarre. Maybe the International Astronomical Union can change their designation so we don't have to keep calling them *inferior* planets.

Contact me about my strange universe by visiting **http://skymanbob.com.**

FROM OUR INBOX

Black holes clarification

Kudos to Bob Berman for the interesting article "Why everything you know about black holes might be wrong" in the October issue. However, I believe that one of the "myths" that he highlighted is actually true. Objects behind an event horizon cannot escape, regardless how they arrived there or the power of their engines. An observer who escaped from that region would see himself or herself outrunning light beams, an impossibility according to Einstein. — **William Nelson,** Tucson, Arizona

It's a common misconception that nothing can escape from within an event horizon. Certainly light cannot. But that is a boundary only for objects traveling naturally, like photons or infalling bits of star stuff. It does not apply to an object like a rocket that can apply acceleration. A rocket could indeed escape with enough power and fuel, and no, it needn't reach light-speed to do so.

A good analogy is Earth's gravity, whose escape speed is cited as about 7 miles (11 kilometers) per second. This velocity requirement is true for an object heading upward without additional help, like a cannonball fired from the ground, ignoring air resistance. But with continuous rocket acceleration applied, an astronaut could fully leave our planet at a speed of just 1 mile (1.6km) per second, or even 1 mph! The escape velocity is no longer valid.

— **Bob Berman,** Contributing Editor

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

ASTRO**NEWS**

GAIA'S FIRST SUPERNOVA. The European Space Agency's mission to map a billion stars spotted a supernova in a distant galaxy — a first for the spacecraft — during the course of its duties, Gaia officials announced September 12.

POSSIBLE PARTICLE. The Alpha Magnetic Spectrometer (AMS), space shuttle, and a Russian Soyuz capsule, far left, were all docked at the International Space Station shortly after installation of the AMS in 2011. The instrument has already turned up tantalizing hints in its search for exotic particles while orbiting above Earth's atmosphere. NASA

HINTS OF DARK MATTER SEEN

The things we think of as the universe — planets, stars, galaxies — are actually just a small fraction of its total mass. Galaxies spin too fast and move too quickly in clusters, implying a majority of mass is lurking unseen, perhaps as dark matter. Except no one's ever detected it. Until now, possibly.

Earth's atmosphere blocks out many high-energy particles, pushing physicists to space to search. It took 500 scientists some $2 billion and 16 years to get the Alpha Magnetic Spectrometer (AMS) aboard the International Space Station and into the hunt for dark matter. And it gave early hints of a major payoff in September.

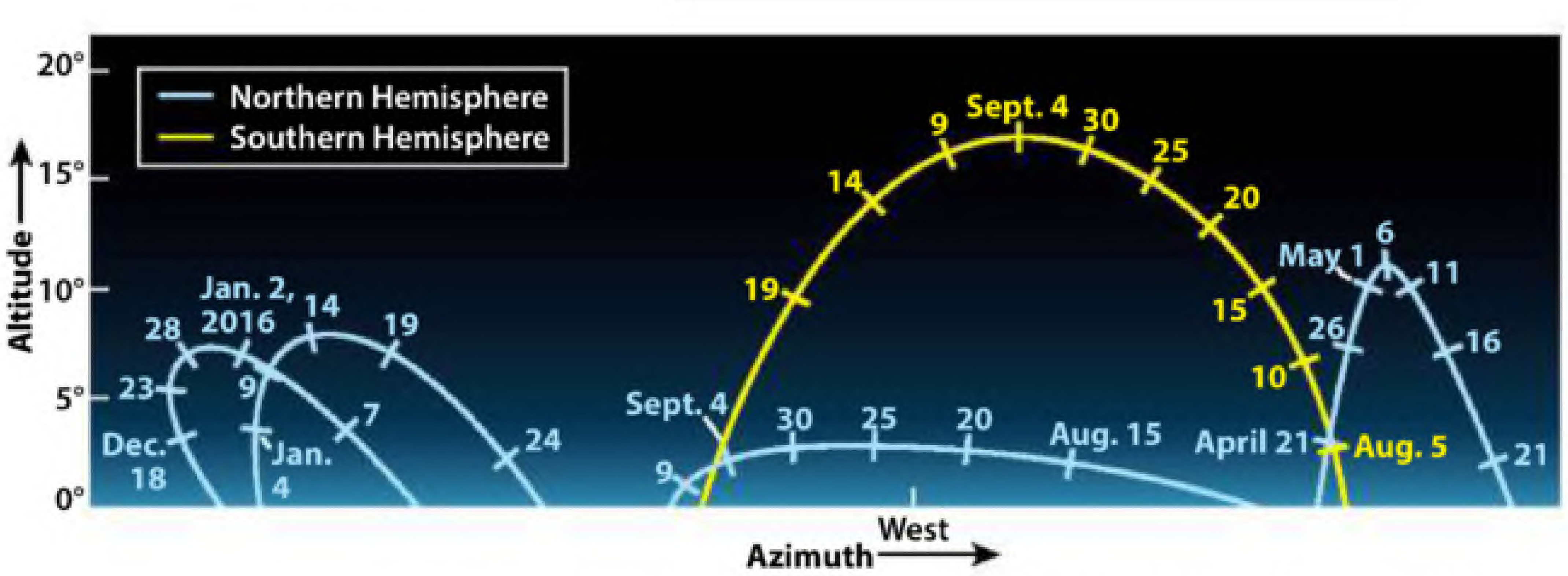
The results were presented at CERN, the European Organization for Nuclear Research, on September 21 and published in the journal *Physical Review Letters*. It's an early analysis of 41 billion particles picked up at energies never before recorded. The AMS saw a drop in the proportion of positrons, followed by a spike and then another drop. Positrons are the antimatter counterpart to electrons, as they carry the same mass but opposite charge. A previously undetected high-energy particle — or even particles — of some sort could be causing this fluctuation, the team believes.

Colliding cosmic rays can produce some positrons, but they likely constitute a minimal portion. That leaves a mysterious amount of positrons unexplained. The scientists were careful to say that it's still too early to declare dark matter has been detected. Still, the discovery is the first time physicists have observed this so-called positron fraction maximum. CERN's Large Hadron Collider will restart and join the AMS in the search this year. — **Eric Betz**

MERCURY IN THE EVENING

From 35° north latitude, Mercury peaks at an altitude of 11.0° May 6; from 35° south, the planet climbs 16.9° high September 4.

FAST FACT



THE ELUSIVE INNER PLANET. Mercury has a reputation for being difficult to see because it typically hugs the horizon during twilight either after sunset or before sunrise. This chart plots the innermost planet's positions 45 minutes after sunset for observers at 35° north latitude during the planet's four evening elongations in 2015. The best conditions occur in early May. For comparison, we also show Mercury's finest Southern Hemisphere appearance, which comes in late August and early September. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY

BRIEFCASE

EUROPA HAS ICY PLATE TECTONICS

Jupiter's moon Europa might be the first world other than Earth known to have plate tectonics. A pair of planetary geologists digitally deconstructed a portion of the moon and then tried to piece it back together. One 7,700-square-mile (20,000 square kilometers) section appeared to be missing. In a paper published online September 7 in *Nature Geoscience*, the planetary scientists propose that their missing section of icy crust was actually subducted under the surface in the same fashion as plate tectonics on Earth. — **E. B.**

•

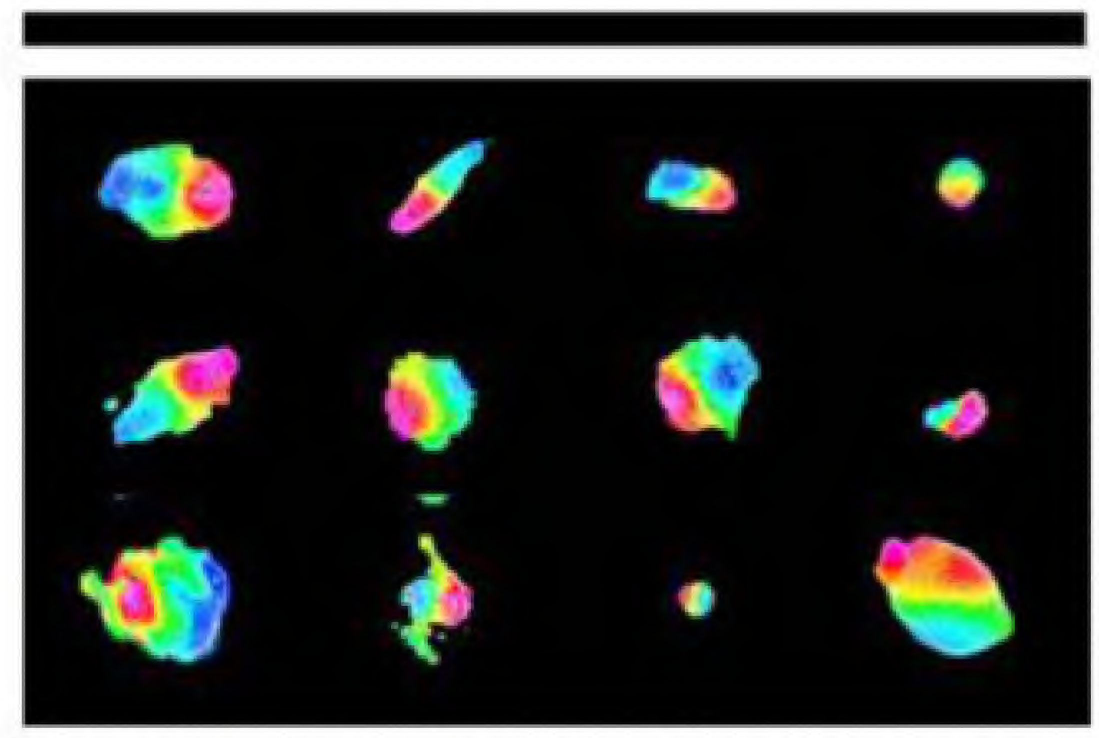
ASTEROID HUNT UNDERSTAFFED

In a report released September 15, the Government Accountability Office detailed growing pains in NASA's asteroid search program. NASA charged the group with finding 90 percent of near-Earth objects by 2020, but it received just $4 million a year between 2004 and 2009. That was upped to $40 million by 2014, partially due to the 2013 Russian Chelyabinsk meteor. The watchdog report found staffing shortages, poor management, lax oversight of grants, and a failure to plan or define objectives. NASA says it will make changes by March. — **E. B.**

•

FLYBY ANOMALIES RAISE FUNDAMENTAL QUESTIONS

Scientists often detect strange and very slight anomalies when robotic spacecraft come in close proximity to Earth. The instruments experience tiny, inexplicable increases in speed. In a paper published in *Advances in Space Research* on August 14, Spanish physicist Luis Acedo Rodríguez explores potential causes from exotic phenomena like gravitomagnetic fields or dark matter, and instead suggests a more common but unconsidered (and unknown) cause is likely. The author says such small discrepancies are important because they have a history of upending long-held beliefs in physics. — **E. B.**



ALMA (ESO/NAOJ/NRAO)/SMA/CARMA/IRAM/J. UEDA, ET AL.

COMPACT DISKS. Each of the blobs in this graphic is a merging galaxy. Red indicates gas moving away, while blue shows approaching gas. Contour lines indicate how each rotates around its center.

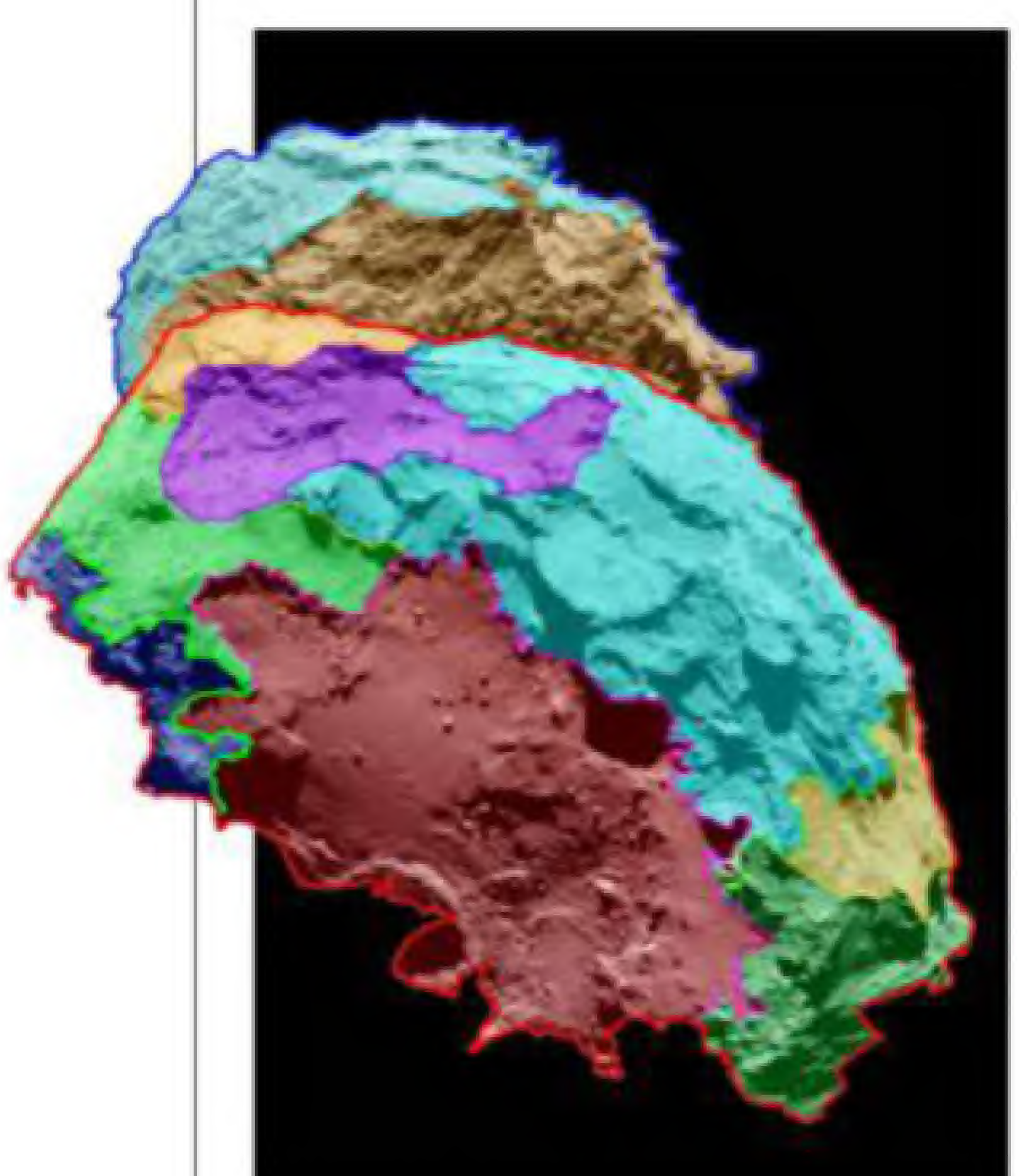
Surprise, merged galaxies aren't elliptical

Textbooks say that two colliding galaxies will merge to produce an elliptical. And that's been the general consensus among astronomers since computer models first projected such grand-scale cosmic collisions in the 1970s. But observational evidence from radio telescopes around the world, backed up by more recent modeling, challenges that long-held belief in results announced in the August *Astrophysical Journal Supplement*. In an analysis of 37 galaxies, the team found 24 mergers had actually ended in disks instead of elliptical galaxies. — **E. B.**

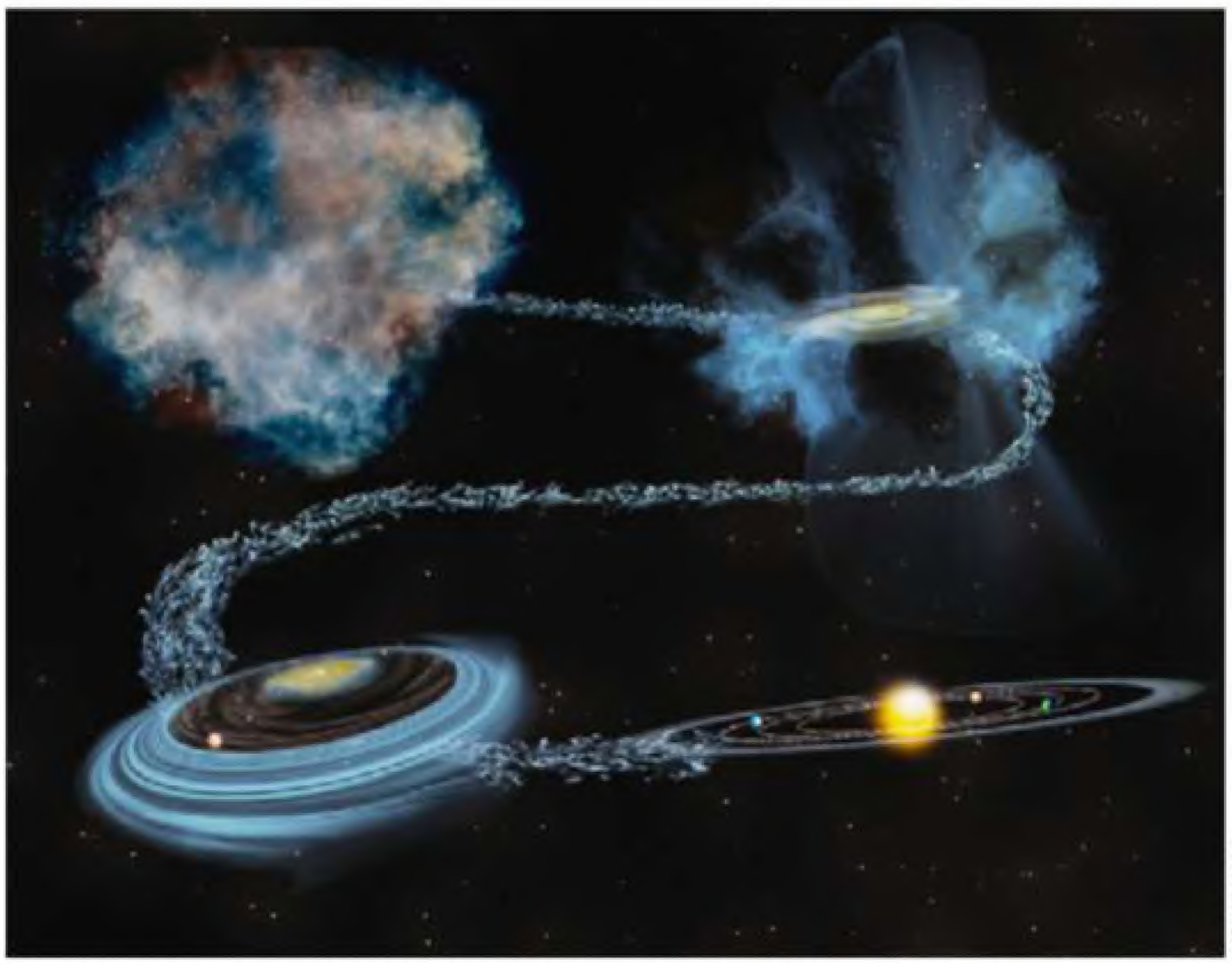
MARTIAN MOUNTAINEERING. NASA's Mars Curiosity rover wheeled its way to the base of Mount Sharp in mid-September. The rover had been headed toward its long-term prime destination for more than a year.

Rosetta mapped in color

The European Space Agency (ESA) released an initial map from the Rosetta mission's target, Comet 67P/Churyumov-Gerasimenko, on September 11. ESA officials say the new map will provide a basis for scientific analysis of the comet's surface. High-resolution images allowed astronomers to identify a number of different morphology types on the city-sized space rock, which is dominated by craters, boulders, cliffs, parallel grooves, and various depressions. Officials say that no comet has been seen at this level of detail before. As the Rosetta spacecraft continues its mission, astronomers expect such maps will help them understand the dynamic history of this solar system traveler. **— E. B.**



MAP-BY-NUMBER. Scientists used high-resolution imaging to map different morphological regions on the Rosetta mission's target, Comet 67P/Churyumov-Gerasimenko. ESA/ROSETTA/MPS



WATER, WATER EVERYWHERE. Astronomers have determined that at least some of the water in our solar system comes from interstellar space ices that predate the Sun. NSF/AUI/NRAO

Some water predates the Sun

One of the key ingredients for life, at least as we know it, is water. It's abundant on Earth, and scientists have discovered it on various bodies throughout the solar system, including moons, comets, and asteroids. But where did this water come from? Did it develop with the planets in the solar nebula surrounding a nascent Sun?

To answer these questions, a team of researchers led by Ilsedore Cleeves of the University of Michigan focused on the ratio of hydrogen to its heavier sibling, deuterium, in water ice found throughout the solar system. They then ran a simulation of the Sun's planet-forming disk without any deuterium in the mix to start with in order to see if the ratio of "heavy water" could reach what it is today.

"We let the chemistry evolve for a million years — the typical lifetime of a planet-forming disk — and we found that chemical processes in the disk were inefficient at making heavy water throughout the solar system," Cleeves says. "What this implies is if the planetary disk didn't make the water, it inherited it." The team conclude in their study, published in the September 26 issue of *Science*, that some fraction of the water in our solar system, including as much as half of the water in Earth's oceans, came from interstellar space and predates the Sun.

And that's not all, according to co-author Conel Alexander of the Carnegie Institution of Washington: "If water in the early solar system was primarily inherited as ice from interstellar space, then it is likely that similar ices, along with the prebiotic organic matter that they contain, are abundant in most or all protoplanetary disks around forming stars." **— Karri Ferron**

Dino-killing impact helped forests bloom

The meteor that killed off the dinosaurs 66 million years ago sparked an impact winter that also altered the fate of every other organism living on Earth. But how did half of Earth's species survive the dramatic environmental change?

Researchers from the University of Arizona and elsewhere looked at 2 million years of fossilized leaves from North Dakota following the impact and found a striking shift in tree populations. Slow-growing evergreen trees died, while the live-fast-die-young deciduous (leafy) trees were able to survive.

The shifting plant populations would have had major consequences for the ecosystems that depended on them. And the impact-driven evolution reshaped the planet into the one we see now, flush with leaves that turn yellow during the fall. The scientists' work appeared in the journal *PLOS Biology* on September 16. **— E. B.**

EVERGREEN ARMAGEDDON. Fossils show that leafy trees were able to adapt faster than evergreens during the long impact winter, giving Earth a colorful fall. JOHAN SWANEPOEL/ISTOCK/THINKSTOCK

QUICK TAKES

PARTICLE CLOUD

"Space bubbles" likely contributed to a 2002 helicopter crash in Afghanistan, according to a Johns Hopkins study. A radio-disrupting nighttime cloud of charged particles had formed in the upper atmosphere nearby at the time.

HISTORY HELPERS

Human computers — often young women — were once crucial to astronomy. In September, Harvard College Observatory asked for volunteers to digitize observers' logbooks to preserve entries.

PLANETARY PEBBLES

The Green Bank Telescope spotted hints of pebbles instead of expected dust in the Orion Nebula. The find could mean a midsize particle class jump-starts planet formation.

COSMIC CRIME SCENE

The Hubble Space Telescope revisited a supernova seen 21 years ago and found the culprit star, NASA said September 9. It confirms that rare type IIb supernovae occur when one star steals mass from another.

EXOPLANET AGES STAR

Like children to human parents, the Chandra X-ray spacecraft has spotted a massive planet that makes its star "act deceptively old," NASA announced. The clingy planet orbits in 23 hours.

SPARKY THE GALAXY

Earth- and space-based telescopes have glimpsed early stages of massive-galaxy formation for the first time, astronomers write in *Nature*. The far-off compact galaxy, dubbed "Sparky," creates hundreds of stars annually.

THIS ONE'S TOO HOT

Scientists searching for Venus-like exoplanets in Kepler data have found a way to distinguish them from Earth-like worlds. Astrobiologists believe distance from a star is more important than size because our twin is so hellish.

MISSING MINI-MOONS

Tiny moons seen at Saturn decades ago are gone, SETI Institute scientists found by comparing to Cassini images. The mountain-sized moonlets are thought to form and then quickly break up. **— E. B.**

SECRET SKY

BY STEPHEN JAMES O'MEARA

Twin treats

Observe some tempting open clusters that offer twice the reward.

As twilight fades this month, the most dazzling open cluster spectacle in all the heavens gradually sizzles into view. I'm referring to the Double Cluster in the constellation Perseus the Hero. You'll find this visually delicious treat in the northern sky roughly midway along an imaginary line drawn between magnitude 3.8 Eta (η) Persei and magnitude 2.7 Ruchbah (Delta [δ] Cassiopeiae).

But did you know that the winter sky holds other intriguing cluster pairs worth contemplating? Here are a few.

In M38's shadow

M38 is a popular sky target that spans 21' and shines at magnitude 6.4 in the central region of Auriga. Only 33' to the south-southwest lies NGC 1907, a forget-me-not open cluster that's easy to overlook owing to its diminutive size (7') and relative dimness (magnitude 8.2).

Despite the disparate sizes of these clusters, astronomers once believed that they formed a true binary system. Their proper motions, however, reveal that they developed in different parts of the galaxy. In the near past, their orbital motions caused them to have a close encounter. We still see them today flying by one another, although they are 1,200 light-years apart.

A near carbon copy

Turn your attention now to another bright Messier open cluster — magnitude 5.1 M35 in Gemini. This beautiful 30'-wide splash of stellar wonder is one of the richest of its kind in the direction away from the Milky Way's center.

Look for the attractive pair of open clusters NGC 1807 (right of center) and NGC 1817 (left of center) in the constellation Taurus. BERNHARD HUBL

Like M38, it too has a tiny (5') and faint (magnitude 8.6) companion cluster, NGC 2158, 26' to the southwest. In this case, NGC 2158 looks small because, at 11,000 light-years away, it is six times more distant than its mate; only because of perspective do we see them as an apparent cluster pair.

An illusion in Taurus?

Now look about 8½° east of brilliant Aldebaran (Alpha [α] Tauri) for another curious pairing of clusters: magnitude 7.0 NGC 1807 and magnitude 7.7 NGC 1817. Separated by only 27' and oriented west-southwest to east-northeast, these mismatched neighbors may not be a pair of clusters after all.

One recent study suggests that they are two star clumps within a single open cluster (which astronomers would designate as NGC 1817). Another provides evidence that NGC 1807 is not a cluster at all, but a chance grouping of unrelated stars in the same region.

A surprise in Cassiopeia?

Cassiopeia has several open clusters of interest. One of its more fashionable ones is M103, which lies 1° east-northeast of Ruchbah. Several other galactic clusters also populate that region, three of which form a popular open cluster arc about 1½° farther to the east: NGC 654, NGC 659, and NGC 663.

NGC 1907 (center) takes second place in this part of the sky only because it lies so near M38 (above center). RICHARD BEST

Despite the close proximity of NGC 663 to NGC 659 (a scant 36'), these clusters have no relation to each other. The twist is that NGC 659 not only has much in common with NGC 654 (including its distance), but it is also a near twin of M103: Both lie about 8,000 light-years distant, measure 6' in apparent diameter, shine around 8th magnitude, contain some 180 members across 15 light-years of space, and have ages between 20 and 25 million years!

The night sky is full of wonderful surprises, sometimes two at once. As always, enjoy the views and send your thoughts to sjomeara31@gmail.com.

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Eric Betz**

Cold as space — Supernova hot

Rocket racket

Three congressmen from contract competitor states demand an investigation of non-taxpayer-funded SpaceX rocket mishaps. The ghost of Robert Goddard gets nervous.

Anchorman in space

NBC orders a new 1960s astronaut comedy series produced by Will Ferrell in which a cocky pilot fights to be first on the Moon. Royalty checks flow to Buzz Aldrin.

Flatlanders

Physicists at Fermilab begin space-jiggle tests to find out if the universe is actually just a 2-D hologram. Sane people wonder: What if the Flat Earth Society was right all along?

The tiniest telescope

Ten thousand fans tell Lego to build a Hubble Space Telescope kit. Inspired, NASA finishes the Webb in tiny plastic blocks and ships it off for an on-time 2014 launch.

TUPUNGATO/ISTOCK/THINKSTOCK (ROCKET RACKET); NASA (ANCHORMAN IN SPACE); NONGKRAN_CH/ISTOCK /THINKSTOCK (FLATLANDERS); GABRIEL RUSSO/LEGO IDEAS (THE TINIEST TELESCOPE)

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ASTRONEWS **"IMMENSE HEAVEN."** Our Milky Way is part of an unfathomably large group of galaxies containing 100 million billion suns in 100,000 galaxies, according to a paper in *Nature*. Astronomers named the "ginormous" supercluster Laniakea.

SPACE SCIENCE UPDATE

LOFTY GOALS, LOFTIER BUDGETS FOR HUMAN SPACEFLIGHT

ROCKETS AT THE READY. NASA prepared for the Orion Crew Module's first flight test in September. NASA/BEN SMEGELSKY

It stands as high as the tallest tree in the world and represents a loftier goal than spacefaring nations have attempted in a generation. NASA's Space Launch System (SLS) got official approval for development in late August, making it the first such American space vessel to advance since the space shuttle.

And the only thing more intimidating than SLS' aim is its astronomical budget. The American space agency says it will spend $12 billion just to reach a test launch for the first phase of SLS, currently scheduled for 2017. But an audit by the Government Accountability Office (GAO) released last summer found the project already short on funds and unlikely to meet the announced deadlines. Outside experts have projected the total cost could reach many times that of the first phase alone.

By comparison, rough estimates say the 135 flights of the Space Shuttle Program ultimately cost taxpayers nearly $200 billion, or about $1.5 billion per flight.

Meanwhile, NASA's separately built but related Orion Multi-Purpose Crew Vehicle was prepped for initial tests in September. The new craft will launch atop SLS to carry up to four crewmembers and cargo.

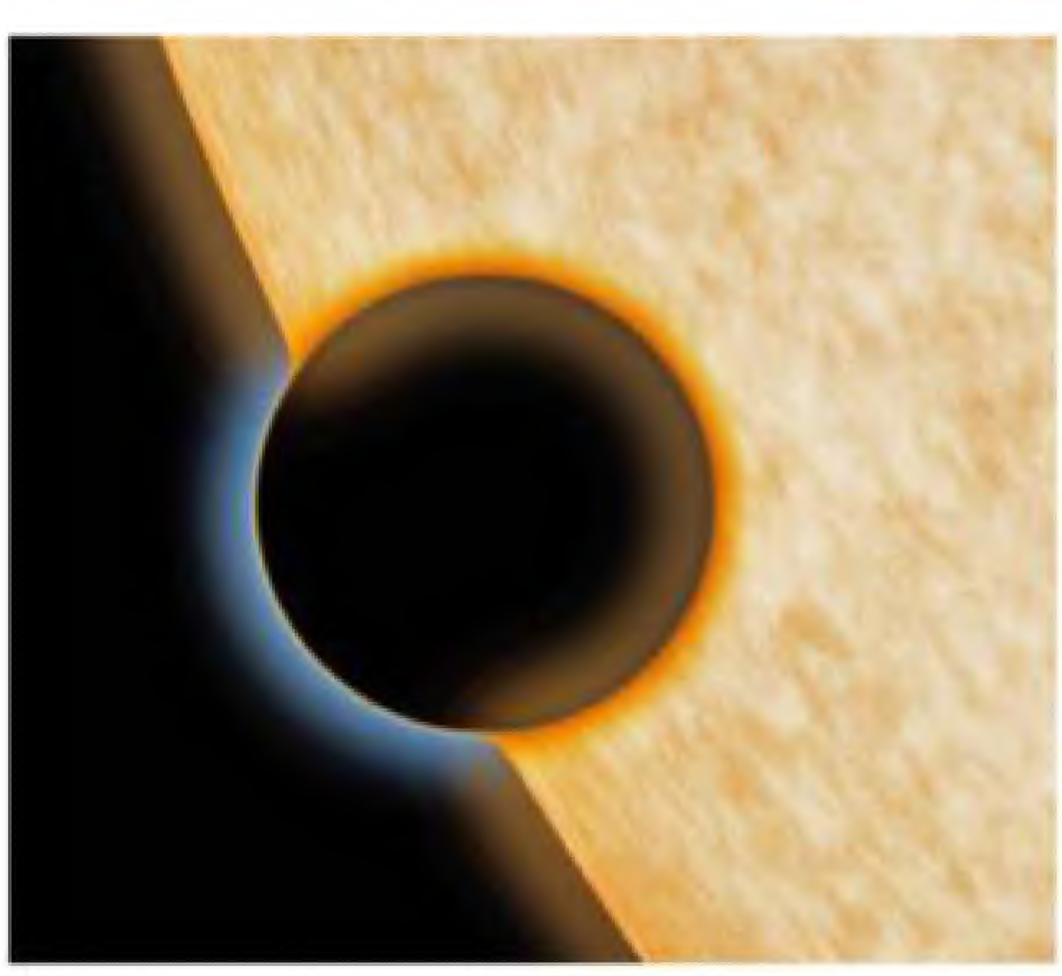
NASA's latest goal is to bypass the Moon and instead send humans to an asteroid and then Mars. An earlier program with similar aims, called Constellation, was canceled in the face of funding shortfalls and acquisition problems.

To reach these goals, the space agency has shifted its focus out of low-Earth orbit. In September, NASA awarded contracts to SpaceX and Boeing for $2.6 billion and $4.2 billion, respectively, to build and fly "taxis" to the International Space Station (ISS).

But NASA drew criticism when it struggled to articulate why Boeing would receive significantly more funds than SpaceX did for the same service. SpaceX has already built and flown a simple version of its future taxi to the ISS, but Boeing has not. Sierra Nevada Corporation, which was the only contract competitor not awarded taxpayer funds, filed a protest bid to investigate the process. The GAO is expected to make a decision on the motion by January. The company will continue work on its Dream Chaser spacecraft even without the contract.

Despite the milestones, commercial spaceflight suffered major setbacks in October. Virgin Galactic's SpaceShipTwo crashed while testing a new fuel, killing one pilot and seriously injuring another. A smaller version of the spaceplane won the X Prize a decade ago by crossing the boundary of outer space, and the company had hoped to finally begin flights for customers this year. The crash came days after Orbital Sciences' Antares rocket exploded carrying supplies to the ISS. Questions soon emerged about the company's use of 40-year-old Soviet rocket engines to fill a $1.9 billion ISS contract. Both companies launched investigations. — **E. B.**

Water vapor detected on Neptune-sized world



WATER WORLD. A transit, when a planet passes in front of its star from our viewpoint (illustrated here), allowed astronomers to detect water vapor on the smallest exoplanet yet, HAT-P-11b. NASA/JPL-CALTECH

Detecting molecules, including water vapor, in the atmospheres of exoplanets is nothing new to astronomers. They've examined the atmospheric compositions of multiple hot Jupiters — giant worlds that orbit close to their parent stars. But scientists have been less successful studying smaller worlds, including those more like Neptune in size, due to the primary annoyance of any astronomer, amateur or professional: clouds. Multiple observations of Neptune-like exoplanets only revealed hazy worlds, obscuring the composition of their lower atmospheres. Researchers were getting frustrated.

But they finally found clear skies while studying the Neptune-sized planet HAT-P-11b, located 120 light-years distant in the constellation Cygnus. According to a paper published in the September 25 issue of *Nature*, this world has become the smallest exoplanet studied to show a signature of water vapor in its atmosphere. The authors, including Heather Knutson of the California Institute of Technology, conclude that HAT-P-11b's atmosphere might not be unlike those of the giant planets in our solar system: mostly hydrogen but with some oxygen in the form of water vapor.

More importantly, the find allows astronomers to breathe a sigh of relief and move forward with studying even smaller worlds. "The work we are doing now is important for future studies of super-Earths and even smaller planets," Knutson says, "because we want to be able to pick out in advance the planets with clear atmospheres that will let us detect molecules." — **K. F.**

ASTRO**CONFIDENTIAL** BY KARRI FERRON

WHAT ARE WE LEARNING ABOUT EXOPLANET HOST STARS?

Elliott **Horch** Professor of physics at Southern Connecticut State University

COURTESY ELLIOTT HORCH

Now that detailed information about many planetary systems is becoming available, some important questions have developed: Is our solar system typical? In what kinds of stellar environments do exoplanet systems exist? And are there "other Earths" — small rocky exoplanets at an appropriate distance from their host stars to permit the existence of liquid water, essential to a biology like our own?

While we are just starting to find answers to these questions, some surprising initial results have emerged from NASA Kepler satellite data. For example, we now know that exoplanets can orbit members of dense star clusters. Likewise, several studies have shown that exoplanets can orbit one of the two stars in some binary star systems. Plus, there are examples of a planet with a wide orbit that encircles both stars in a close binary system. In all of these cases, the planet's orbit could in theory be perturbed and eventually destroyed by the gravitational interaction with other members of the cluster or the second star in the binary system. Yet exoplanet systems with stellar companions appear to be much more durable than we previously believed.

My colleagues and I have completed a new study that focuses specifically on how often confirmed or suspected exoplanet host stars have a close, previously unknown stellar companion in addition to the planetary one. In most cases, the second star would be farther away from the host star than the planet itself, but still bound to the primary star. Using high-resolution imaging techniques at the Gemini North and WIYN telescopes and searching for companions as close to the exoplanet host star as these telescopes allow, we have found that stellar companions are just about as common in exoplanet systems as in cases where a star does not have a planet — nearly half in either case have stellar companions. This means that for many worlds outside the solar system, not one but two suns shine in the sky: a nearby star around which the planet orbits and a more distant sun in a wide orbit around the exoplanet system.

ASTRO**NEWS**

GAS RESERVOIRS. Astronomers using the Cassini mission unraveled how methane rainfall runoff on Saturn's moon Titan creates systems of lakes and seas that mix with aquifers. Their paper appeared September 1 in *Icarus*.

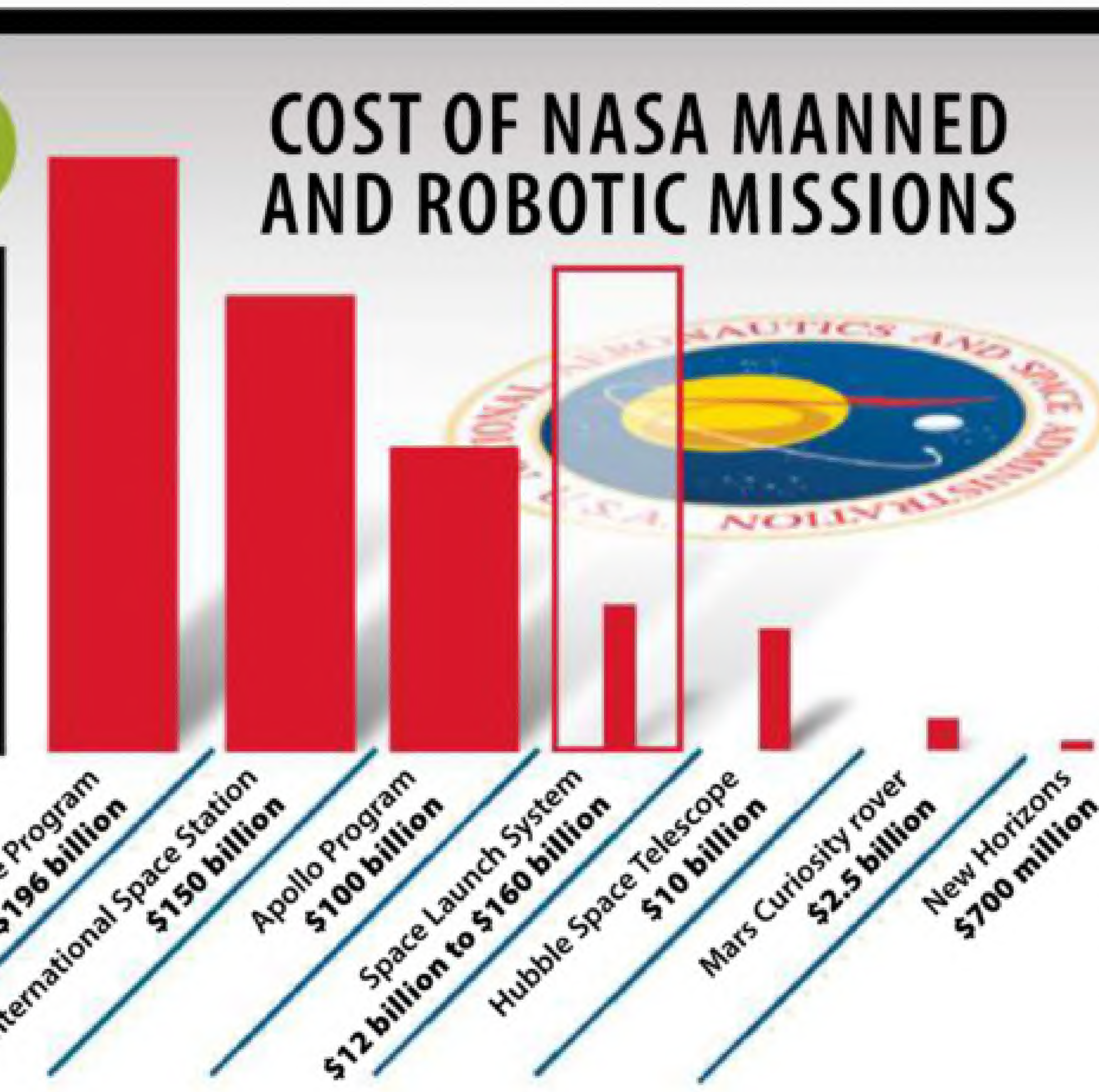
ISRO

New orbiter sees signs in the sand

RED PLANET RORSCHACH. India became the first Asian nation to reach Mars orbit when its spacecraft arrived at the Red Planet on September 24, just days after NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft. And while the Indian Space Research Organization's instrument package was considerably less sophisticated than the one NASA placed in orbit, the Indian craft accomplished its test mission on a shoestring budget of $74 million. As the Mars Orbiter Mission sent back this initial photo of the Red Planet, Indian scientists and citizens were quick to point out the shape of their home country in the dust storms brewing below. — **E. B.**

FAST FACT

Since the final shuttle flight in 2011, NASA has sent 13 astronauts to the largely U.S. taxpayer-funded ISS in Soyuz capsules, as compared to Russia's 19.



LAUNCH MONEY. Operating budgets and unforeseen events make it tough to pin down the lifetime cost of a space mission. This chart compares the best available estimates adjusted for inflation. The development of America's newest manned mission, the Space Launch System, is currently over budget at $12 billion with expert estimates ranging as high as $160 billion to reach its goals.

ASTRONOMY: ERIC BETZ AND ROEN KELLY

25 years ago in *Astronomy*

The decade's first issue looked forward to a new era of exploration, one defined by space telescopes and missions to the outer solar system, as then Assistant Editor David J. Eicher detailed 50 scheduled spacecraft. And on the eve of the Hubble Space Telescope launch, scientists planned what would happen when the mission ended in 2005. The discussed replacements included a 30-foot or Moon-based telescope. That mission is now called the James Webb Space Telescope, and its mirror will come in at 21 feet (6.5 meters). — **E. B.**

10 years ago in *Astronomy*

In January 2005's "Second Light," Contributing Editor Steve Nadis wrote about our universe's earliest stars, those from Population III and Population II. It's thought that these early metal-poor suns — born from just hydrogen and helium — were hotter, brighter, and many times bigger than the ones we see in our universe today. But as they evolved, these ancestors of our Sun created the materials that would allow for things like planets and eventually people. — **E. B.**

OBSERVING**BASICS**

BY GLENN CHAPLE

Time travel

Better relate to stellar distances by connecting them to earthly events.

At a winter star party, a participant points toward Sirius and asks, "How far away is that star?" Someone replies, "8.6 light-years," and then briefly explains what a light-year is. Since the distance to Sirius in light-years is the same as the travel time for its light, I like to enhance this answer by noting what earthly events were taking place when the light reaching our eyes exited its surface.

Sirius is the closest of seven stars of 1st magnitude or brighter currently visible after dark from mid-northern latitudes. Listed in order of increasing distance, they are Sirius, Procyon, Pollux, Capella, Aldebaran, Betelgeuse, and Rigel. How far away are they? Our answers include each star's distance in light-years based on parallax measures made by the Hipparcos satellite, followed by a look at what was happening on our home planet when its light departed for a 2015 arrival.

Sirius (8.6 light-years): What was going on in late May 2006 when the light from Sirius began its 50.6-trillion-mile (81.4 trillion kilometers) journey earthward? NASA's Cassini spacecraft was in the process of discovering lakes of liquid methane or ethane on Titan's surface, while Pluto was in its last months as an officially recognized planet. From your perspective, a personal or family-related milestone like a graduation, wedding, birth, or death might have overshadowed these events. Depending on your age, you'll likely recall lifetime experiences for each of the next four stars.

Procyon (11.4 light-years): When Procyon's light left around mid-summer 2003, astronomers were enjoying close-up views of Mars as the Red Planet made its nearest approach to Earth in centuries. If you're a member of the high school class of 2015 anticipating a June graduation, consider this. Back then, you were about to enter first grade. Most of your entire elementary/high school education is written on a beam of light from Procyon!

Pollux (34 light-years): Light from Pollux departed early in 1981 at the same time the Space Shuttle Program opened with the orbital test flight of *Columbia*. The Reagan era in American politics was beginning, and Saturday evenings brought us the escape shows *Love Boat* and *Fantasy Island*.

Capella (42 light-years): Space aficionados remember 1973 (when Capella's light took flight for Earth) as the year Comet Kohoutek (C/1973 E1) was discovered and Skylab, the first U.S. space station, was launched. Veterans of the Vietnam War will note that 1973 was the year direct U. S. military involvement in this conflict finally ended. *All in the Family* was the top-rated TV show, and many of today's middle-agers were disco dancing beneath a rotating mirror ball.

Aldebaran (65 light-years): In 1950, the year Aldebaran's light began its earthly journey, Dutch astronomer Jan Oort proposed the existence of an orbiting cloud of comets (now called the Oort Cloud) at the outer reaches of the solar system. If you've arrived at retirement age (typically, mid to late 60s), Aldebaran shines in your honor. Its ruddy light left around the time you were born, continued onward as you went to school, began a career, got married, and had children and then grandchildren. It finally arrived just as you retired — literally the journey of a lifetime!

Betelgeuse (640 light-years): When it comes to accurately knowing a star's distance, we now enter a realm of uncertainty. The parallax of Betelgeuse is so minuscule that even Hipparcos satellite measurements are iffy. The currently accepted figure means the photons striking your retinas left during the latter part of the 14th century. Since none of us was around then, we have to rely on historical events. When light left the surface of Betelgeuse, China's Ming Dynasty had begun, the Aztecs were settling in what is now Mexico City, and the European Renaissance was in its infancy.

Rigel (860 light-years): Rigel's distance is variously reported as between 700 and 900 light-years, with a Hipparcos measurement hinting at 860 light-years. Imagine a star so luminous that it ranks seventh in brightness in our nighttime sky even though the void separating us is so vast that its light has been traveling since the middle of the 12th century! When we look at Rigel, our eyes are picking up starlight launched earthward around the time of the early Crusades.

Defining a star's distance by the events occurring on Earth when its light began its journey adds a dimension not achieved by mere numbers. Later this year, we'll revisit the distance/history link with a look at summer stars.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: What's in a name? Clear skies!

FROM OUR INBOX

Gravity and quantum mechanics

I would like to thank James Trefil of George Mason University (August "Ask Astro," p. 35) for an excellent response to the very difficult questions about the relationship between gravity and quantum mechanics. To laypeople such as me, it was helpful for him to highlight the problems with melding gravity and quantum mechanics by explaining that general relativity interprets gravity geometrically, whereas quantum mechanics interprets the other basic forces of nature dynamically. It was also helpful when he said that superstring theory and quantum loop gravity theory attempt to interpret all four fundamental forces as dynamical. Too bad general relativity has made so many amazing, accurate predictions while string and quantum loop fall a bit short presently.

— **Robert Walty,** Stephens City, Virginia

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

SPACE PAPARAZZI. Images taken over a decade show rarely photographed planet formation around a star 335 light-years from Earth.

STEFFEN RICHTER, HARVARD UNIVERSITY

POLAR RIVALS. Two instruments seeking similar results, BICEP2 (left) and the South Pole Telescope (right), are housed in the Dark Sector Lab less than a mile from the geographic South Pole in Antarctica.

Satellite data deflates BICEP2 discovery

You can't re-cork a champagne bottle, but there are probably a few physicists who now wish they could. Doubts about Nobel Prize-worthy results from an instrument in Antarctica grew in September when the European Space Agency's Planck spacecraft collaboration released their eagerly awaited data.

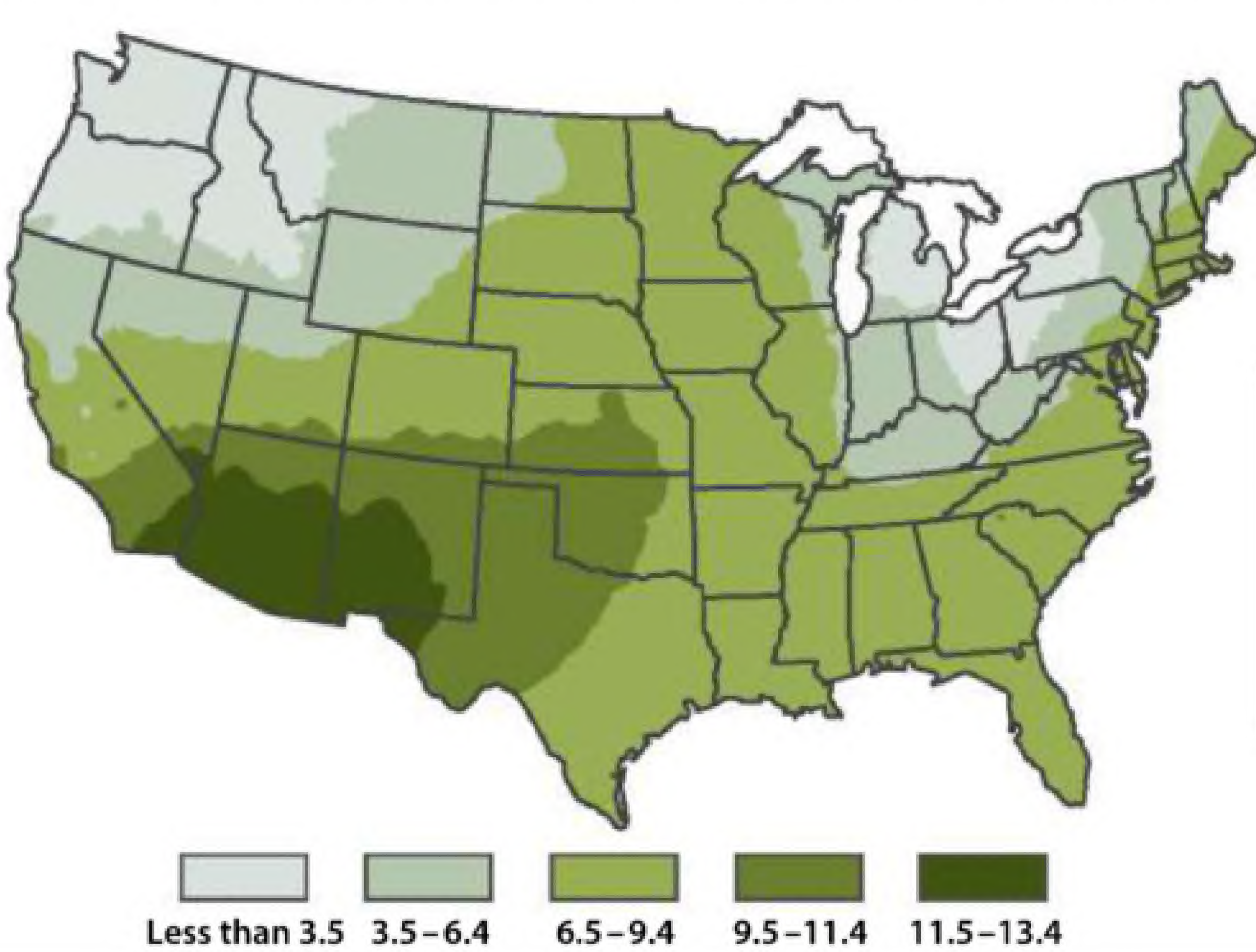
In March, a group running the BICEP2 telescope had published research indicating that they had glimpsed the first physical evidence of inflation, a fundamental theory of the Big Bang that details a rapid expansion of the universe in its first few fractions of an instant. A race has been on in recent years to find the proof. While few dispute inflation, critics of the BICEP2 results emerged soon after the initial announcements. Many suggested that the telescope might have picked up galactic dust instead of the widely sought polarization of the cosmic microwave background.

The Planck collaboration released early data in September that added to the evidence that BICEP2 had merely picked up noise in our Milky Way Galaxy. These Planck results have been submitted to *Astronomy & Astrophysics* for peer review. Planck and the BICEP2 team now will work together in an attempt to align the two sets of results. Meanwhile, scientists working on a rival instrument in Antarctica, the South Pole Telescope, also are hoping to separately find evidence of inflation. — **E. B.**

300 LIGHT-YEARS

The diameter of the smallest galaxy ever found with a central black hole, announced September 17 by scientists using the Hubble Space Telescope.

AVERAGE NUMBER OF CLEAR DAYS IN JANUARY



FAST FACT

January may be the second-cloudiest month, but its sky contains the brightest constellations.

ASTRONOMY: MICHAEL E. BAKICH AND ROEN KELLY, AFTER NOAA

COSMIC**IMAGING**

BY ADAM BLOCK

Using masks, part 3

I have now covered enough material in past articles that we can combine several simple techniques to powerfully process data. In this column, we will take what we learned about creating object masks (see November's and December's columns) and a properly prepared luminance image (see October's column) to blend a sharpened image with its original, slightly blurred self.

What imagers refer to as "deconvolving an image" often results in as many artifacts as benefits. The primary goal is to use a mask to reveal only the good (artifact free) parts of a sharpened layer. Typically, the areas of low signal show signs of "curdling" of the uniform noise grain, and areas of discontinuity, especially around bright stars, show a ringing effect.

The first step is to sharpen the image using a deconvolution algorithm. Monitor only the features you want to sharpen (not the brightest stars — see below). Most programs have a version of the Lucy-Richardson algorithm, which I recommend because it iteratively converges on solutions by making the image sharper as it goes along. Generally, you will specify a point-spread function by clicking on stars in the image to begin. I'll explain getting the best results from deconvolution in a future column.

ALL IMAGES: ADAM BLOCK

One of the author's first steps was to copy the original image and paste it into a layer mask. To view an online version of NGC 6365, go to http://skycenter.arizona.edu/gallery/galaxies/ngc6365.

Once you have a sharpened version of your image, you must permanently stretch it (see October's column again) and the original in the same way so that you can blend them in Photoshop. One thing to remember is not to let your bitmap values exceed 200 grayscales.

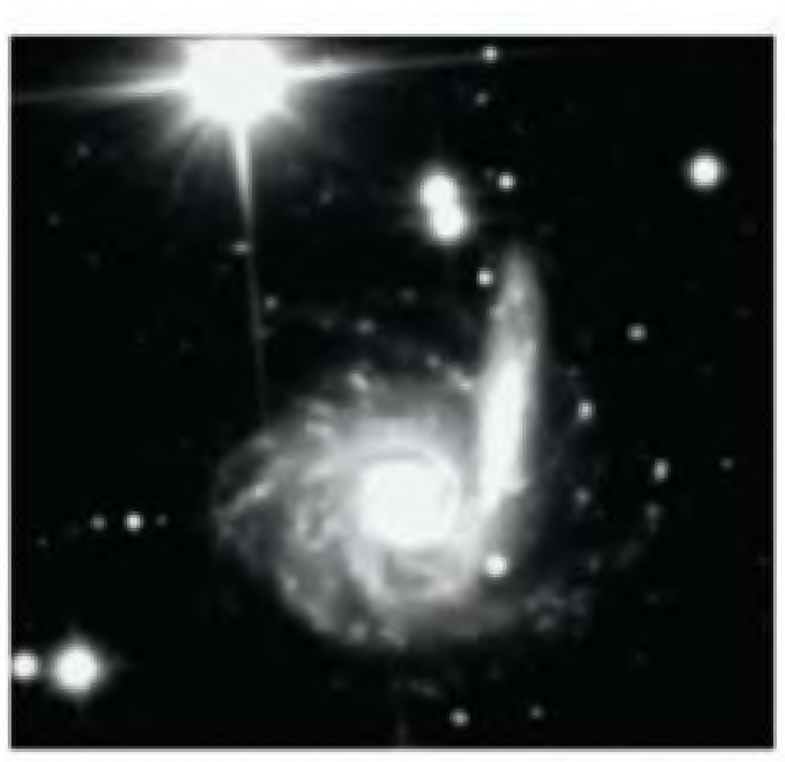
Save these two images as TIFF files, and open them in Photoshop. Copy the sharpened image, and paste it onto the original image so that you have two layers. Next create a new layer mask for the sharpened (upper) layer. Paste a copy of either layer into your layer mask. You now have an object mask, and your screen should look like the image at top left.

The key is to adjust the object mask so only the brightest parts of the upper sharpened layer show and noisier aspects are hidden. The layer mask is nicely in the correct grayscale scheme with the object(s) being white and the background black. By using "Levels," adjust the mask so that everything you want sharpened is white in the mask.

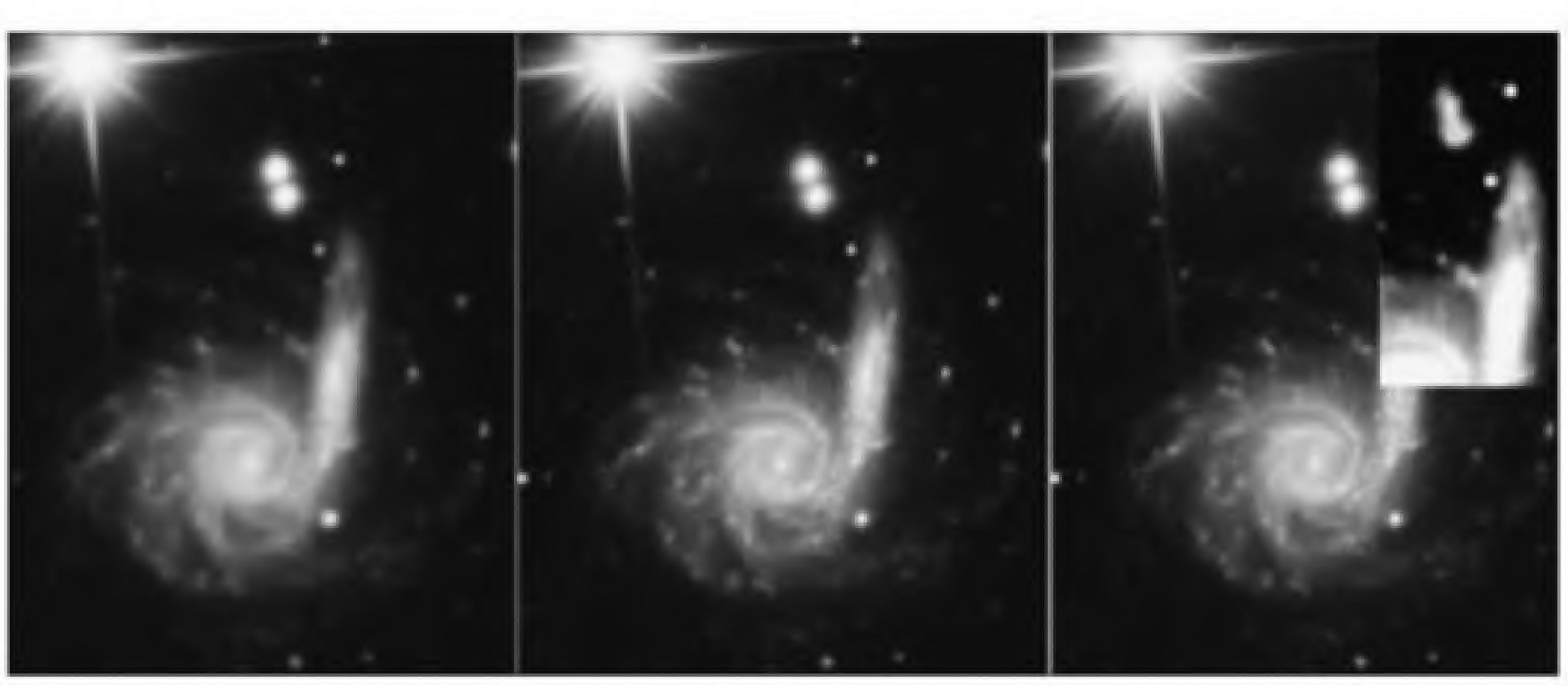
Let dimmer regions of the object remain gray, and raise the black level to completely clip the faintest parts of the image (see below left), but don't turn it all black and white. It is important to keep some gray features so that there will be smooth transitions between the upper layer and the original image in the final result. You can improve these transitions by applying a small Gaussian blur of 3 to 4 pixels in strength to the mask, but it isn't always necessary.

When you do the above, the ring artifacts and harsh edges of the brightest stars will remain. Saturated stars do not have the profile you expect, so they suffer when you sharpen the image, and the object mask reveals them. Generally, they are few enough to manually fix. Using the "Paint Brush" tool, circle the edges of the bright stars in black on the object mask. This will hide the artifacts and show the original star profile (see the sequence at left). Paint with a 50 percent brush opacity for finer blending control.

In a few minutes, you will have a virtually artifact-free sharpened image of your favorite deep-sky object! In my next column, I will show you one of the most satisfying processing techniques there is — manipulating an image in the "Lab" color space.



Your second major step will be to adjust the mask by clipping both the background and brightest features. For this mask, the author applied a 3-pixel Gaussian blur.



After you use software to sharpen the image to the left of this sequence, the galaxy improves dramatically (above left), but the bright stars — like the double star above the galaxy — have undesirable processing artifacts (center). The right frame shows how the author painted on the mask (inset at right) to hide the rings around the stars and reveal the original stars with a sharpened galaxy.

FROM OUR INBOX

Spitzer extension

In "NASA releases project rankings" (September 2014, p. 21), you mentioned that Spitzer Space Telescope operations will conclude at the end of fiscal year 2015. As the public affairs officer covering astrophysics at NASA, I can submit a happy update. In July, the Science Mission Directorate made the decision to extend Spitzer operations for the next two years. The Spitzer observatory is an important resource for ongoing infrared observations for research programs across the Science Mission Directorate, and subject to the availability of congressional appropriations in fiscal year 2015, it will be continued. Both the Astrophysics and the Planetary Science Divisions have requested observing time commitments for fiscal year 2015, and both divisions have committed funding to support their observations. The Spitzer project has been given direction to continue planning for operations into fiscal year 2016. — **Felicia Chou,** Washington, D.C.

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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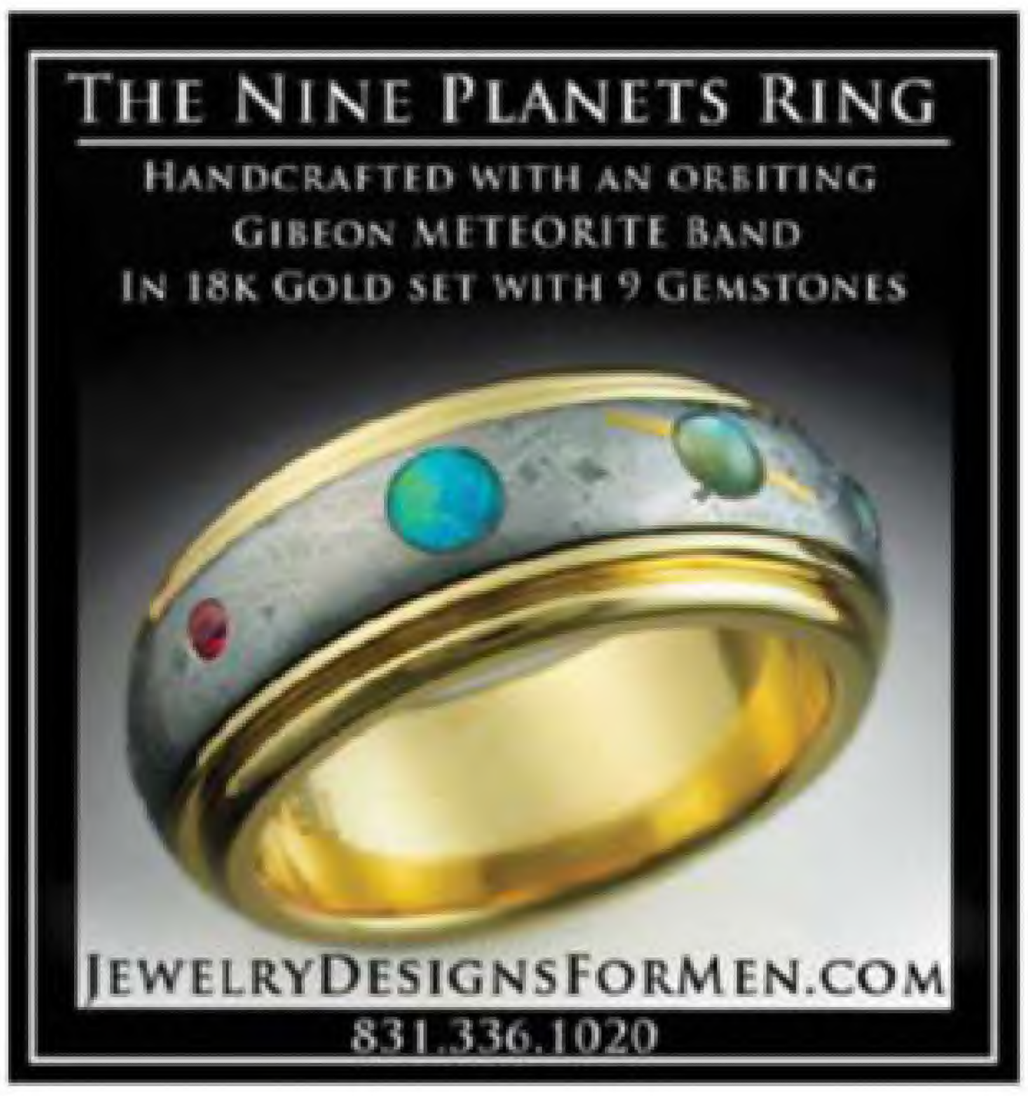
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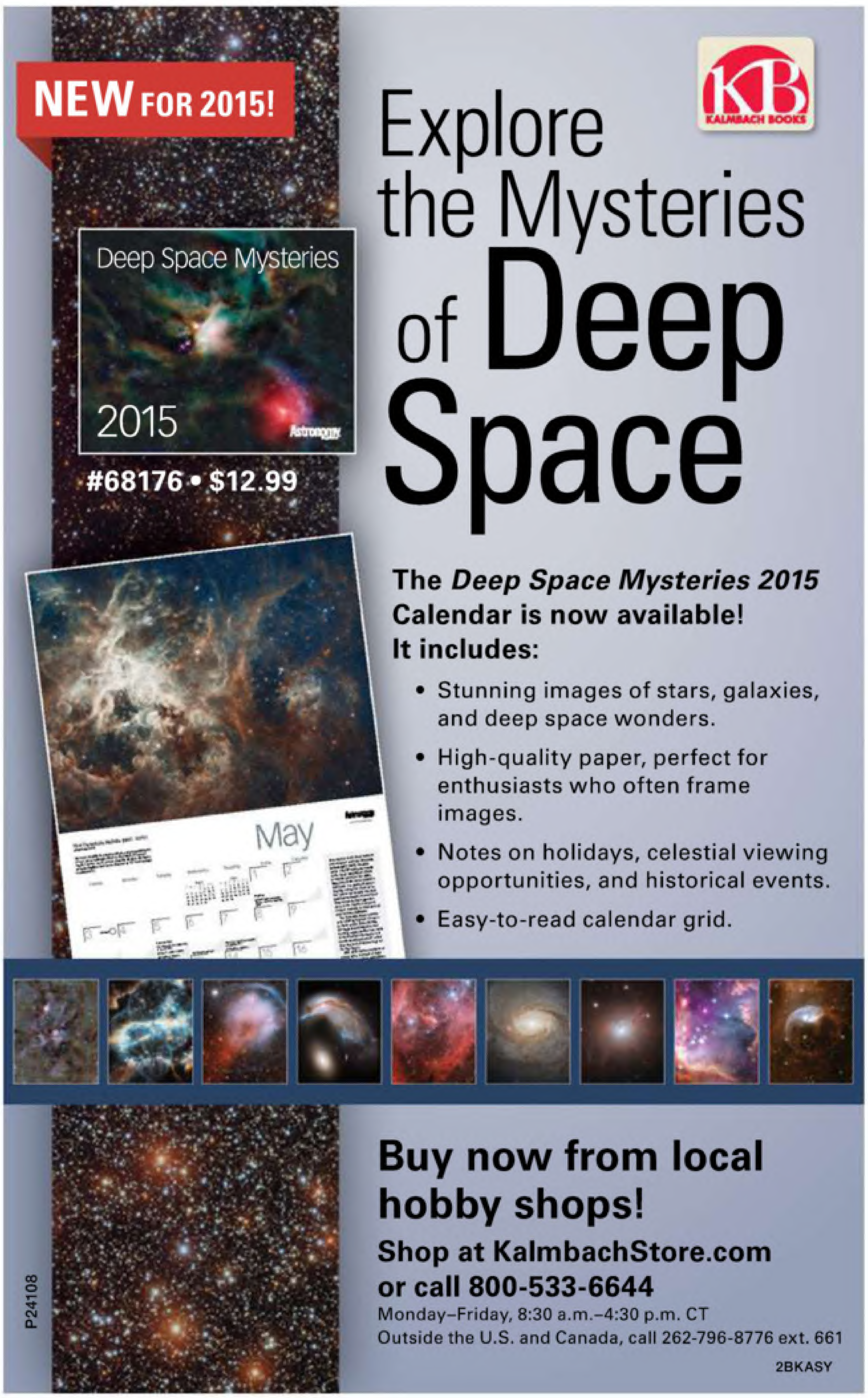
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BY KARRI FERRON

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Seasonal Observing

Find great targets in your winter sky

Winter skygazing is a double-edged sword for Northern Hemisphere observers: The nights are the longest, giving you ample time to explore the sky, but it's also the coldest time of the year, making it difficult to log those long observing sessions. For this reason, it's important to plan your time under the stars. That's where the Astronomy.com winter observing videos come in.

Each season, *Astronomy*'s editors provide you with three videos outlining showpiece objects currently in the night sky. Senior Editor Michael E. Bakich gears one winter video toward beginning observers and easy targets, such as Venus, Mercury, and the Quadrantid meteor shower. In another, he focuses on objects you can see through a small telescope, including the Tau Canis Majoris Cluster (NGC 2362). And finally, Editor David J. Eicher shares 10 of his favorite winter deep-sky objects, such as the Jellyfish Nebula (IC 443) in Gemini. Check out all three observing guides at **www.Astronomy.com/seasons**.

OBSERVING TOOLS

Astronomy's "Sky Guide 2015"

Subscribers can start planning for important 2015 observing events with exclusive access to a digital version of *Astronomy*'s "Sky Guide 2015." In 16 pages, Senior Editor Richard Talcott and Contributing Editor Martin Ratcliffe provide a month-by-month synopsis of planet visibility, Moon phases, meteor shower peaks and predictions, eclipses, and more. This handy guide will be a resource you'll return to again and again throughout 2015. Download it now at **www.Astronomy.com/skyguide**.

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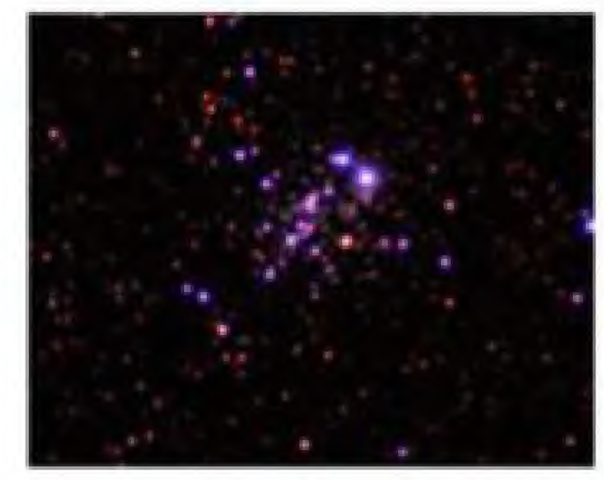

Browse thousands of beautiful astroimages like this one of the Owl Cluster (NGC 457) by Kevin Witman. Submit your own images at **www.Astronomy.com/readergallery**.

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The biggest astronomical discovery of 2014 involved how dust forms in the universe. Studies revealed that supernovae, like SN 1987A illustrated here, produce this material.
ALEXANDRA ANGELICH (NRAO/AUI/NSF)

Top 10 space stories of 2014

Scientists discovered a Lake Superior below Enceladus' surface, found another dwarf planet in the solar system, and mapped a million galaxies to give them a precise measurement of the universe's expansion.

by Liz Kruesi

Every day, the editors of Astronomy have the privilege to learn what scientists are uncovering about our cosmos. With sophisticated instruments scouring the skies from Earth's surface and space, it's no surprise that this past year saw dozens of major astronomical discoveries. The trick was picking just 10 to place in our annual countdown of the top stories of the past year.

Planetary science had an especially strong showing in 2014, with further research on Saturn's moon Enceladus, Jupiter's moon Europa, two smaller solar system bodies, and objects beyond Pluto's orbit. But cosmology had an exciting year, too, including a much debated possible confirmation of a period of hyperacceleration in the early cosmos — the inflationary epoch. Another important study seemed to slide quickly by most news media outlets, although it was an impressively accurate measurement of a million distant galaxies.

These stories and several other important discoveries appear on the following pages.

Liz Kruesi *is an* Astronomy *contributing editor and freelance writer who covers all things space-related from Austin, Texas.*

Using the European infrared satellite Herschel, scientists found water vapor erupting from the surface of the asteroid Ceres, as shown in this illustration. ESA/ATG MEDIALAB

10 Water vapor seen at two worlds

Astronomers this past year spied the telltale signature of water in the tenuous atmospheres of two solar system objects: Jupiter's moon Europa and the asteroid Ceres.

While scientists have loads of evidence that Europa hosts a global ocean below a thick ice crust, the new observations suggest that some process launches that liquid into space. Lorenz Roth of the Southwest Research Institute in San Antonio and colleagues used the Hubble Space Telescope's spectrograph to split apart and analyze the ultraviolet light reflected off material near Europa. They found hydrogen and oxygen in the atmosphere of the moon's southern hemisphere, which they think results from water molecules (each made up of two hydrogen atoms and one oxygen atom) colliding with electrons, causing the molecules to break apart.

The researchers saw the hydrogen and oxygen signals when Europa was at its farthest point from Jupiter in its orbit but didn't see the elements when the moon was closest to the planet. The differing amounts suggest the water vapor erupts from Europa as the planet's mass pulls on the satellite and opens cracks in the surface. According to their study in the January 10 issue of *Science*, Roth's team compared their observations to computational models to find that two plumes, each 120 miles (200 kilometers) high, could create the material Hubble spied.

Meanwhile, a study published the same month in *Nature* described infrared detections of water vapor around the largest asteroid in the solar system, Ceres. This object lies in the main asteroid belt between Mars and Jupiter.

Michael Küppers of the European Space Astronomy Centre in Spain and colleagues used data from the European Space Agency's Herschel satellite to locate possible water sources on the asteroid, the first detection of water vapor on any object in the asteroid belt. They think the liquid erupts through the surface in jets, similar to what happens on comets. If additional studies can confirm this idea, it would further blur the line between asteroids and comets.

NASA's Dawn spacecraft is currently en route to Ceres and set to arrive in April of this year. If water is spewing from multiple spots on the asteroid, the craft will see them.

9 Scientists find neutrinos from celestial sources

Chargeless and nearly massless particles called "neutrinos" interact weakly with matter. This property makes them difficult to detect, but when researchers do find them, neutrinos can tell scientists a lot about their sources. Physicists first detected neutrinos in the 1950s, and now, six decades later, they've captured much higher-energy ones, introducing a new class of these particles.

8 Black holes *do* come in intermediate masses

A debate that has raged for decades may have been finally put to rest, and it concerns some of the most bizarre objects in the cosmos: black holes. These extremely dense bodies have such strong gravity that anything that passes too near — including light — gets pulled in forever.

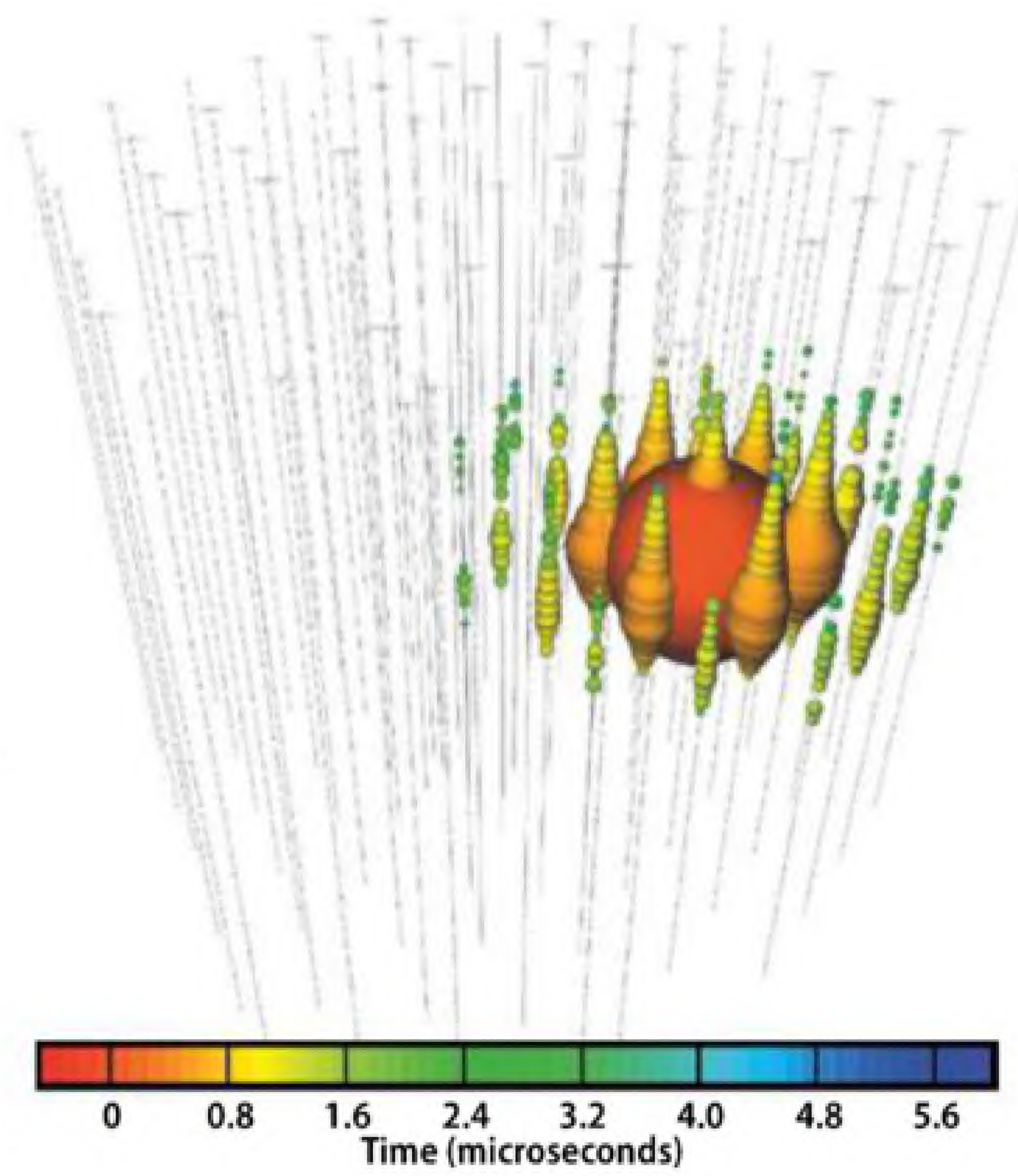
While astronomers can't yet directly observe a black hole, they know these objects exist based on material orbiting them. Using basic laws of physics — the same laws that govern how the planets orbit the Sun — researchers have known for years that black holes come in two varieties: stellar mass (those a few to about 30 times the Sun's mass) and supermassive (those millions to billions of times the Sun's mass). But the ones

Researchers needed a gigantic instrument to make the discovery. Embedded in a cubic kilometer of pristine ice at the South Pole lie 5,160 individual modules that make up the IceCube neutrino detector. After spending a year analyzing the instrument's first two years of data, IceCube scientists announced their big find in the November 22, 2013, issue of *Science*: high-energy neutrinos from cosmic sources. The team confirmed the discovery using a different analysis technique and announced this result April 7, 2014, at the American Physical Society meeting.

Most of the neutrinos that IceCube detects result from the showers of particles created as high-energy cosmic rays slam into molecules in Earth's atmosphere. But the energies of about 80 neutrinos seen so far are much higher than those created during the showers. Instead, these particles must have formed in cosmic explosions or other high-energy events. The high-energy neutrinos detected so far have more than 10 trillion times the energy of visible light, and two have even 100 times that value. "Our neutrinos have a million times the energy that we saw from Supernova 1987A or from the Sun," two other neutrino sources, says IceCube Principal Investigator Francis Halzen of the University of Wisconsin-Madison.

To measure a neutrino's energy, astronomers analyze the light captured by IceCube's individual modules. If the neutrino that passed through the detector is of the muon variety, the scientists can trace its position back to within 0.4° on the sky. If instead the neutrino is an electron type, the precision lies between 10° and 15°.

Unfortunately, the IceCube team hasn't detected enough muon neutrinos to accurately track the particles' sources. Possibilities range from active galaxies to powerful blasts called gamma-ray bursts and even the signatures of dark matter particles, the invisible material that composes most of the universe's mass. "Of course it would be exciting if [these] neutrinos ended up being something that we haven't talked about," says Halzen. "It's perfectly possible."



Hundreds of individual modules within the South Pole's larger IceCube detector captured data from a high-energy neutrino passing through in 2011. The neutrino had an energy about a million billion times that of a visible-light photon. ICECUBE COLLABORATION

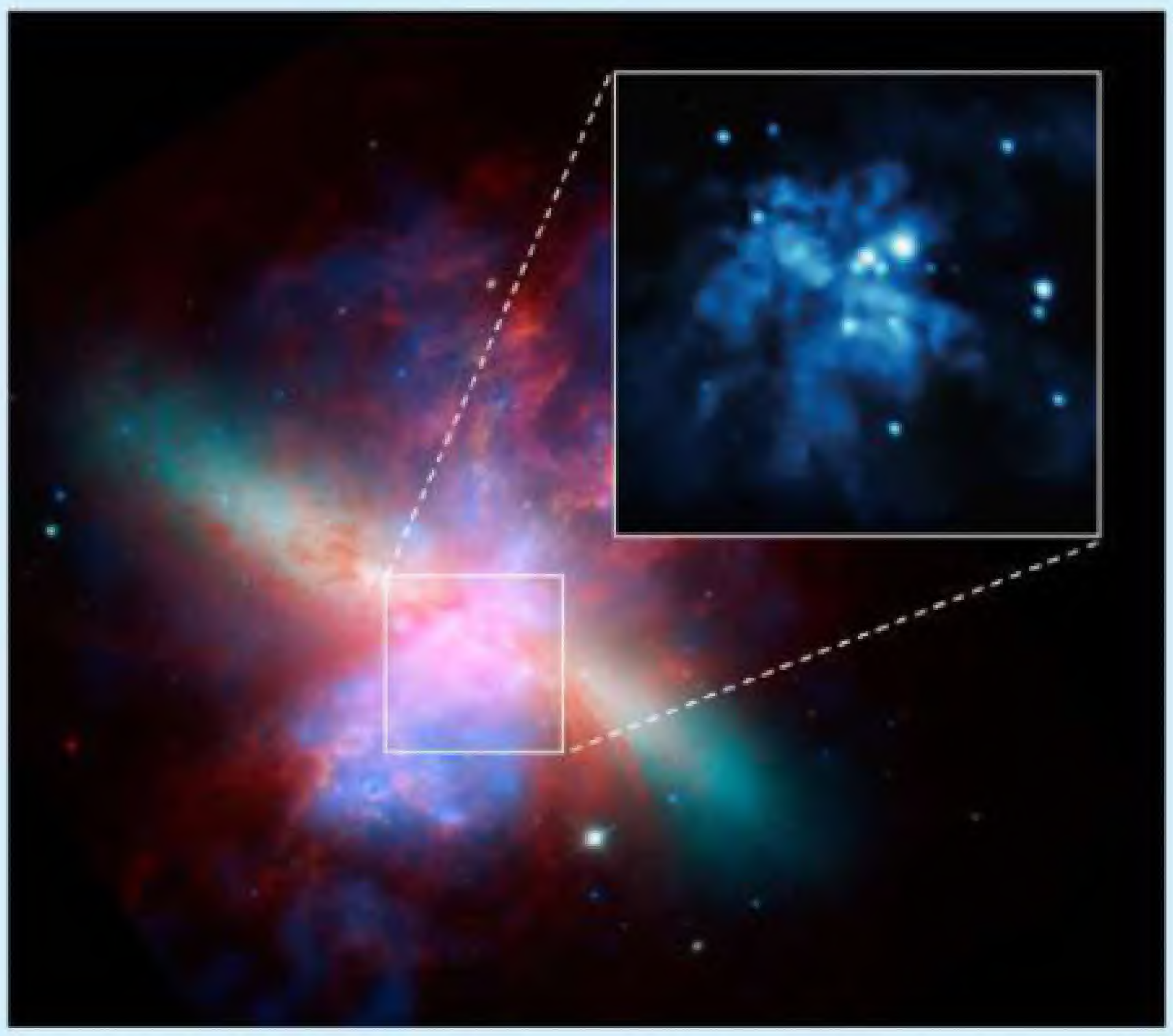
between these extremes proved elusive until this past year. An August 17 *Nature* study gave a mass measurement of a luminous X-ray source in the nearby starburst galaxy M82, called M82 X-1, of 428 solar masses, with an uncertainty of 105 solar masses; that range, 323 to 533 solar masses, defines the object convincingly as an intermediate-mass black hole.

The scientists, led by Dheeraj R. Pasham of the University of Maryland in College Park, used archived data from NASA's Rossi X-ray Timing Explorer. They looked for specific oscillation signals that likely result from material orbiting within accretion disks surrounding black holes. While astronomers don't yet know specifically what these signals come from, they've seen them in many stellar-mass black holes and in some candidate intermediate-mass ones.

The smaller variety of black holes have two pairs of these oscillations, one set that orbits the dense object at a rate of 1 cycle per second (1 hertz) or less and another pair with higher frequencies. The latter pair always seems to follow a 2:3 ratio. Researchers have found a few candidate intermediate-mass black holes with their own duos of the low-frequency oscillations, but these show up at rates of about 0.0001 Hz. Why the difference? "If the black hole is more massive, then the size scales in the accretion disk are bigger," explains co-author Tod Strohmayer of NASA's Goddard Space Flight Center in Greenbelt, Maryland. "The idea is that a bigger black hole will have lower-frequency oscillations than a lower-mass black hole." But no one had seen the high-frequency oscillations in candidate intermediate-mass black holes.

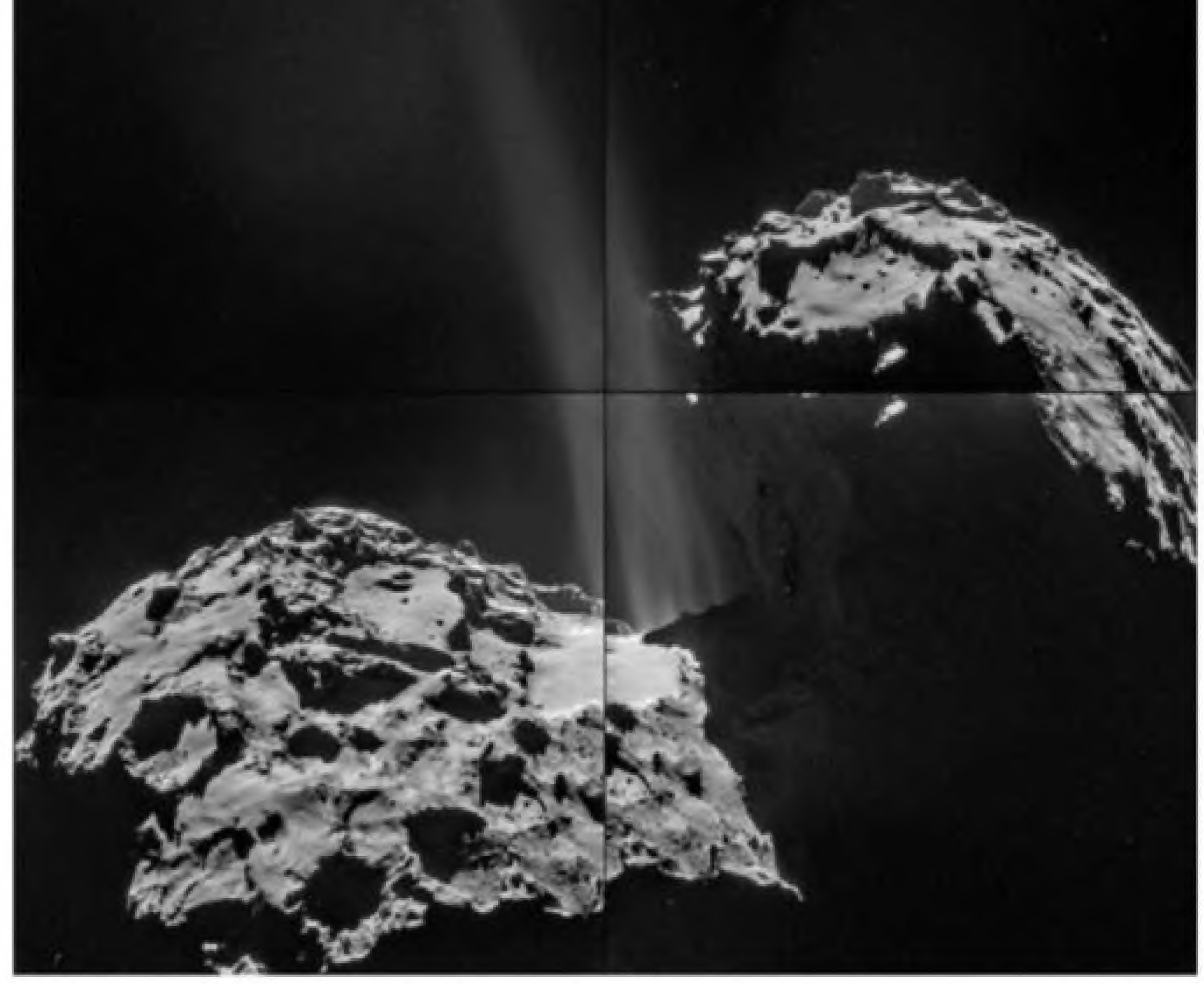
Pasham's group looked at data collected from M82 X-1. They found the high-frequency oscillation pair at 3.3 Hz and 5 Hz, following the same 2:3 ratio, which "gives us confidence that these are the same signature that we see in stellar black holes," says Strohmayer. "By comparing those frequencies, we can make estimates of the mass. And we get that mass of about 400 solar masses."

This study gives the strongest piece of evidence yet that middle-of-the-road black holes exist. They seem more rare than stellar-mass and supermassive ones, although specifically why is a major question, too. Future X-ray instruments — like the Neutron star Interior Composition Explorer, set to arrive at the International Space Station in 2016 — will help astronomers learn more about this now-confirmed class of objects.



Near the center of starburst galaxy M82 lies an intermediate-mass black hole with a mass of about 400 Suns. This black hole shows up as the brightest dot in the inset X-ray image. X-RAY: NASA/CXC/JHU/D. STRICKLAND; OPTICAL: NASA/ESA/STScI/AURA/THE HUBBLE HERITAGE TEAM; INFRARED: NASA/JPL-CALTECH/UNIV. OF ARIZONA/C. ENGELBRACHT (M82); X-RAY INSET: NASA/CXC/TSINGHUA UNIV./H. FENG, ET AL.

7 Rosetta's comet rendezvous



This Rosetta mission mosaic from September 26 shows gas escaping from the neck of Comet 67P/Churyumov-Gerasimenko due to ice sublimation.

On August 6, following a 10-year journey, the Rosetta spacecraft became the first probe in history to orbit a comet. While the mission's journey with Comet 67P/Churyumov-Gerasimenko has only just begun, Rosetta's observations already have surprised scientists. In July, once the craft was close enough to Comet 67P to resolve it across multiple camera pixels, Rosetta showed that the comet has a double-lobe shape, like a duck, with a distinctive body and head.

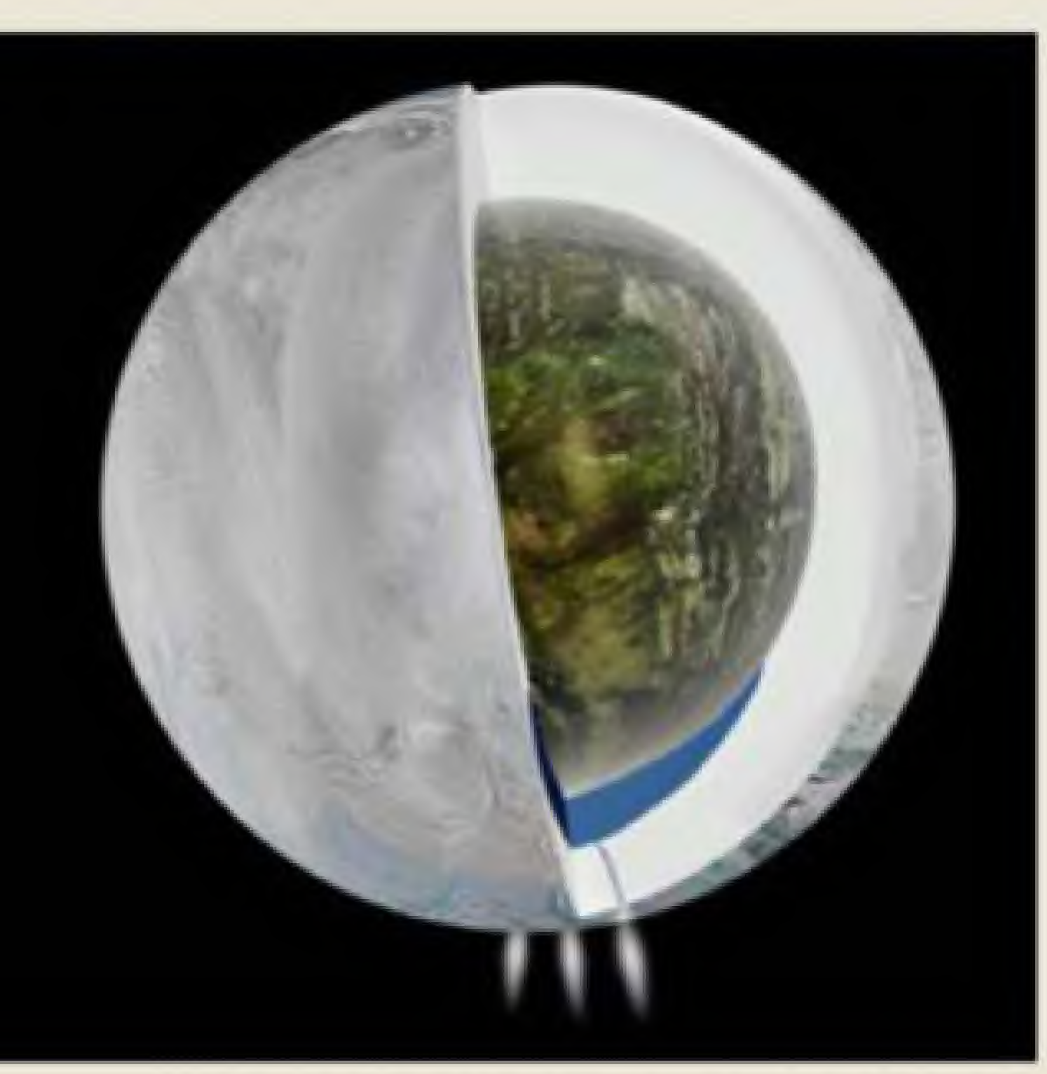
As of early October, Rosetta team members had seen most of the comet's nucleus. From these observations, they think Comet 67P's large lobe measures 2.5 by 2.0 by 0.8 miles (4.1 by 3.2 by 1.3 kilometers), while the smaller portion is 1.6 by 1.6 by 1.2 miles (2.5 by 2.5 by 2.0 km). Researchers also have measured the comet's mass, which allows them to calculate its density — 0.4 g/cm^3 (for comparison, Earth is nearly 14 times denser).

In addition to figuring out the comet's major characteristics, Rosetta is equipped with instruments to collect and analyze dust. So far, it has grabbed a few dozen dust particles. Scientists expect the craft to capture much more dust once the comet and Rosetta near the Sun, whose heat will turn the comet's ices to gas. This process pulls dust off the nucleus, and the dust and gas show up as a surrounding "coma" and a tail. The Rosetta orbiter and its Philae lander, which will study the comet's surface for a few months, will witness this transition first-hand.

The spacecraft's camera suite has seen a few plumes of gas shoot out from Comet 67P so far. And the mission has tasted water, carbon monoxide, carbon dioxide, ammonia, methane, and methanol and measured different amounts of these gases depending on where the probe is in its orbit around the comet.

Rosetta will stay at Comet 67P for another year and monitor all changes that the comet experiences as it reaches its nearest approach to the Sun in August 2015.

6 Enceladus has a subsurface sea



According to new research using NASA's Cassini spacecraft, Saturn's moon Enceladus has a sea of water below its icy surface, as shown in this illustration. NASA/JPL-CALTECH

When NASA's Cassini spacecraft arrived at Saturn in 2004, scientists couldn't have dreamed of the number of discoveries it would make. Yet one of the most exciting finds it has had isn't of the planet, rather one of its moons. In early 2005, Cassini spied plumes of water erupting from the south polar region of Enceladus. To date, the probe has observed 100 of these jets. But where does the water come from?

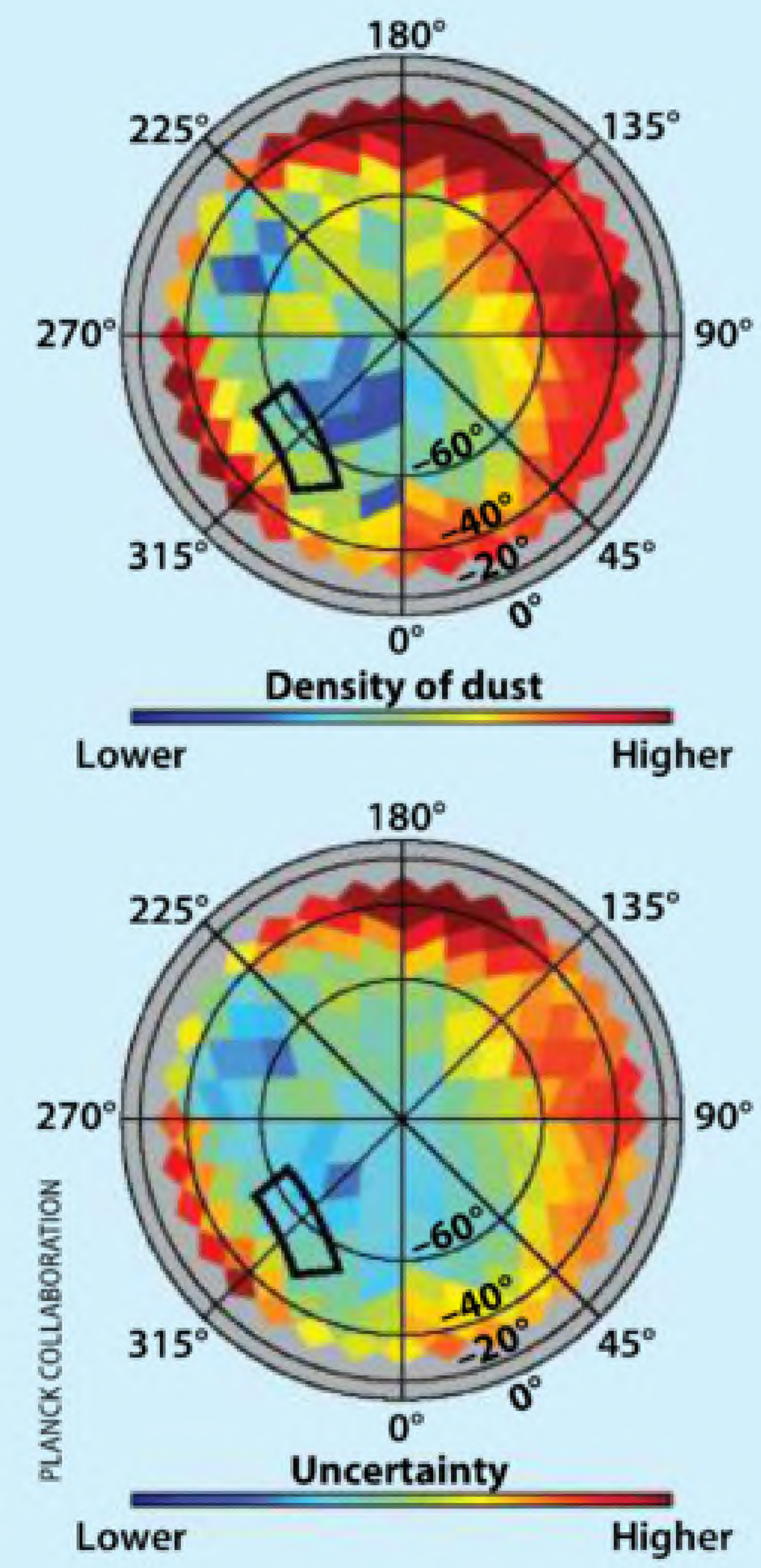
A study published in the April 4 issue of *Science* suggests that the saturnian satellite has a huge reservoir of water below its icy surface, feeding the plumes. And data from Cassini gave scientists the information they needed to calculate the sea's size, depth, and density.

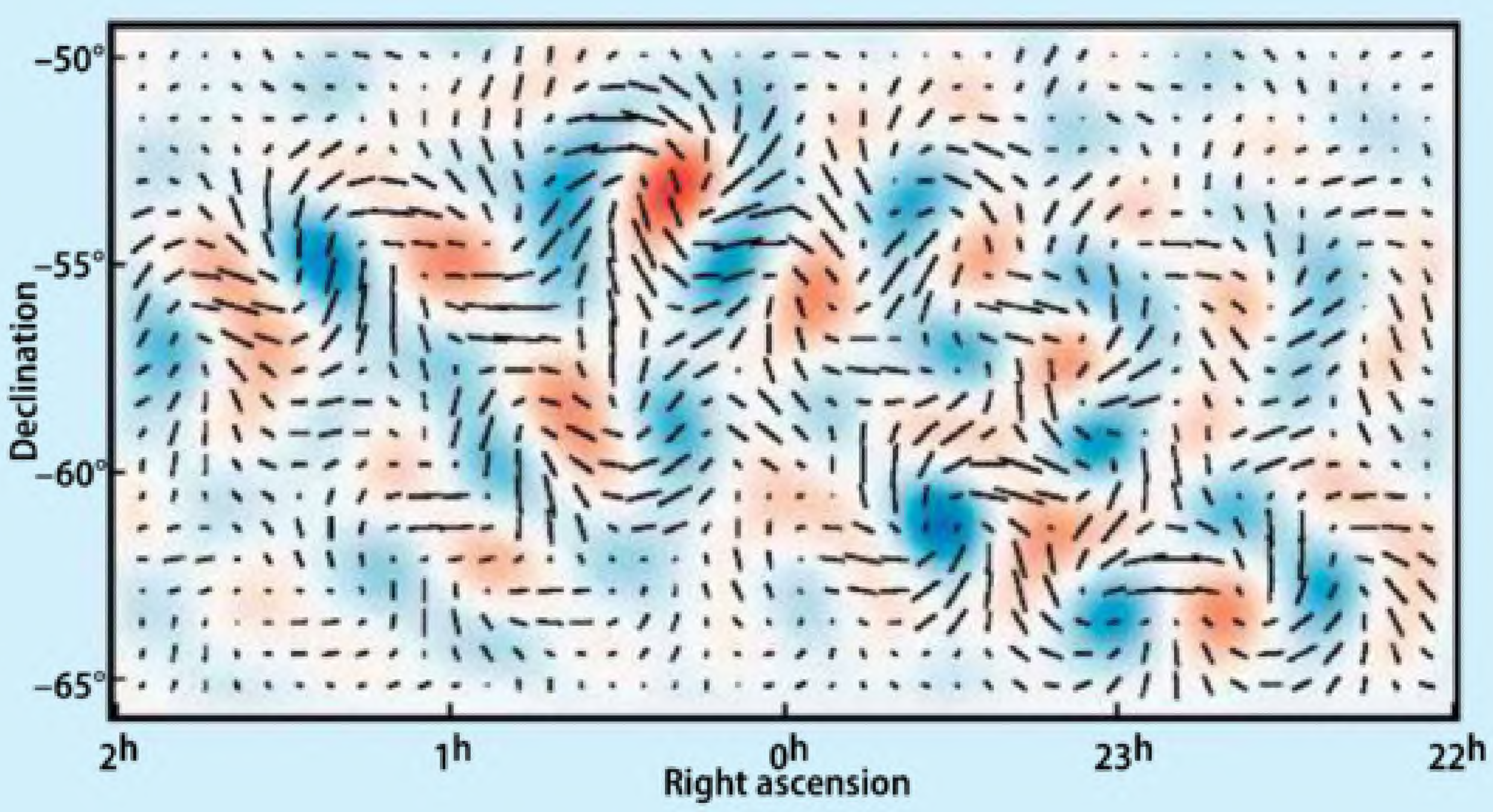
Luciano Iess of the University of Rome La Sapienza and his colleagues tracked Cassini as it flew within 60 miles (100 kilometers) of Enceladus' surface. The more pull the probe felt, the more mass was directly below it. This relationship allowed the scientists to calculate Enceladus' gravity field, but first they had to take into account the gravitational tugs from other bodies in the solar system, the radiation pressure from the Sun, the radiation pressure from the probe's onboard energy source, and the drag that Cassini felt as it passed through the geysers.

Iess' team then compared the moon's mass distribution to topography measurements of its surface. Those previous measurements showed that Enceladus has a large dent, or depression, about 0.6 mile (1km) deep near its south pole. But the new gravity measurements show there's too much mass in that region. The most likely explanation for this difference, say the scientists, is a large body of water. Water is about 8 percent denser than ice, and thus the same volume would weigh more.

Iess says a reservoir with "about the amount of mass contained in Lake Superior" lies below a 25-mile-thick (40km) ice shell. This underground lake stays warm from the push and pull of Saturn's gravity (in the same way Earth and the Moon have tides from each other's gravity). But "the mechanism that produces liquid water, and why only at the south pole, is another fascinating topic of investigation," says Iess. Meaning, they don't yet know what keeps this moon geologically active.

5 Cosmic inflation observation bites the dust?





The BICEP2 instrument located at the South Pole imaged a twisting pattern on the sky, which team members think may be the result of hyperacceleration in the universe's first second. BICEP2 COLLABORATION

Planck mission scientists mapped the Milky Way's dust across the sky. The top map shows the dust contribution from just one angular scale in the Southern Hemisphere, and the bottom map shows the uncertainty of that measurement. The BICEP2 field of view is outlined in black.

As soon as the Harvard- Smithsonian Center for Astrophysics announced a March 17 press conference for a major discovery, excitement began to swirl. Researchers with the BICEP2 telescope, which scans the microwave sky from the South Pole, claimed they had detected the signature of ripples in space-time created during the universe's first moments.

Almost immediately, the astronomical community split into two sides. Some scientists heralded the BICEP2 find as the breakthrough of the century. But others doubted that the researchers properly incorporated into their analysis the Milky Way's dust, which would affect the signal they claimed to see. It didn't help that the BICEP2 team made the claim before the research had gone through a peer-review publication process.

The cosmologists said they found a swirl pattern in the cosmic microwave background (CMB) radiation that fills the universe. This light is a remnant of what the cosmos looked like at 380,000 years, when electrons and protons combined to form hydrogen, allowing photons to travel freely across the universe. The CMB carries information of the early cosmos, including how material was moving at the time.

Microwaves, like all light, can oscillate along a preferred direction, a characteristic called "polarization." The early universe's material mix could have imprinted two different polarization patterns on CMB photons. Temperature differences from pressure waves in the hot soupy mix show up as an "E-mode" pattern, like spokes on a wheel. But different types of oscillations called "gravitational waves" — ripples in the fabric of space-time — also create temperature differences. These show up as a fainter "B-mode" signal that takes the shape of swirl patterns.

Theories say that 10^{-37} second after the universe's beginning, the cosmos experienced extreme acceleration called "inflation." The sudden expansion triggered gravitational waves; these are the ripples that cause the B-mode patterns and the signals the BICEP2 team claimed they had found.

The debate stems from dust grains that "align according to the magnetic field of the galaxy," explains BICEP2 team member Jamie Bock of the California Institute of Technology in Pasadena. "They're spinning around the [Milky Way's] magnetic field lines, and that gives them a net polarization." And a dust-induced polarization signal also can show B-mode patterns that mimic those from primordial gravitational waves.

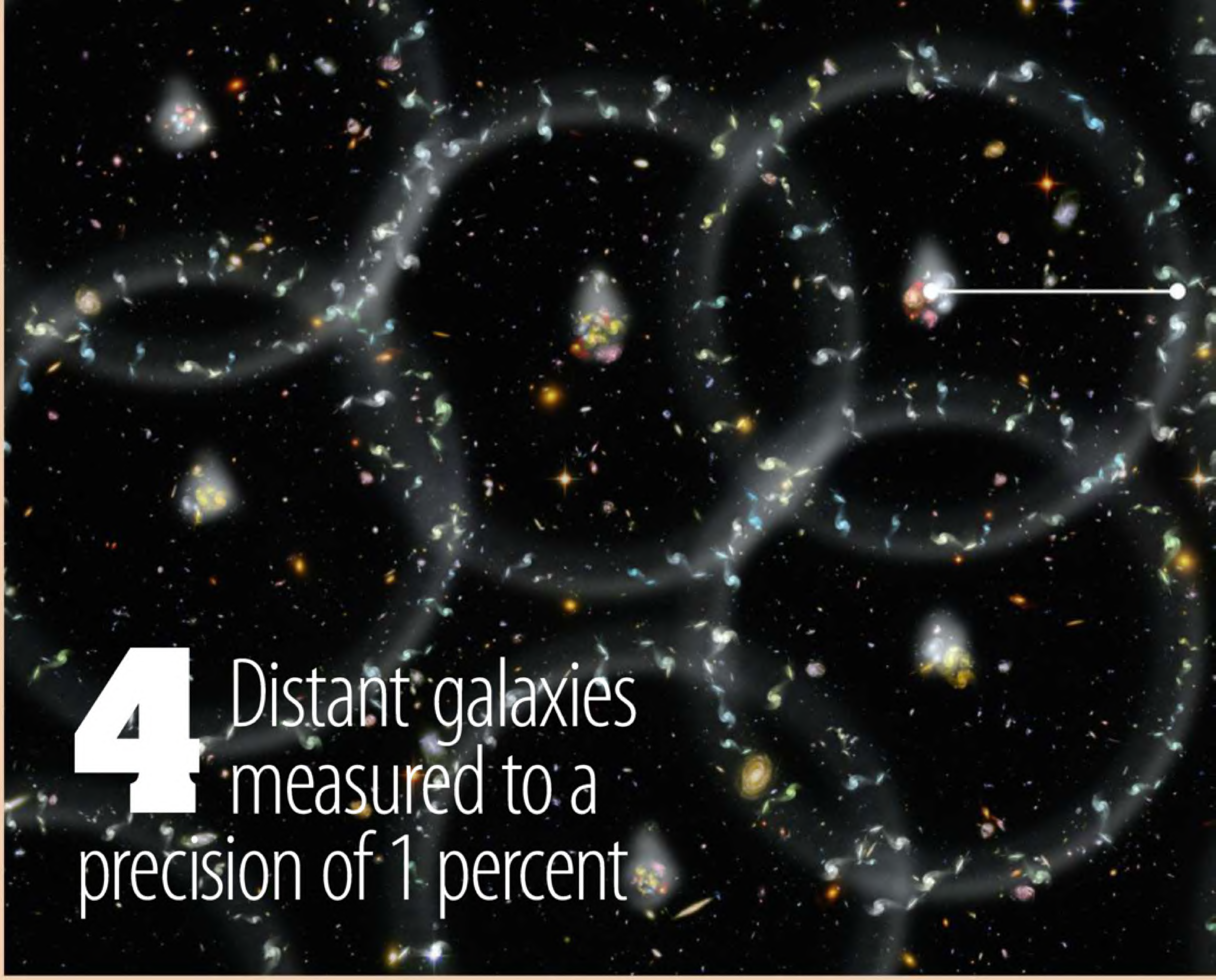
On September 22, astronomers with the European Space Agency's Planck CMB satellite quietly released their analysis of dust across the entire sky. And the news wasn't good for the BICEP2 team.

While BICEP2 observes a small patch of sky at one frequency (150 gigahertz), Planck studied the entire sky across a much wider frequency range: 30 GHz to 857 GHz. Planck scientists measured the amount of dust glowing at 353 GHz because that frequency detects more dust and little CMB signal. The researchers modeled the dust distribution and then extrapolated down to 150 GHz to compare the sky's patchy dust at the same frequency that BICEP2 sees.

"The Planck paper says there is more dust in the BICEP2 field than the BICEP2 team calculated, expected, or took into account in their March paper," says Planck U.S. Project Scientist Charles Lawrence of NASA's Jet Propulsion Laboratory in Pasadena. However, this analysis comes with a lot of uncertainty: "It could be enough dust to account for all of the B-mode polarization signal that BICEP2 sees; it could be enough dust to count for only a small fraction of it."

The debate about the BICEP2 results continues, but this is "science in action," says Lawrence. The BICEP2 researchers "have a good measurement. They have low noise, and they've been very careful about it. They measure B-modes in that field." He adds, "With Planck and also being able to look at characteristics of dust across the sky, you get more information and more of an idea of what's going on. It's a good example of how science works."

The BICEP2 and Planck teams are collaborating to further investigate the dust in the BICEP2 field of view. Astronomers expect to have the analysis completed early in 2015, which will provide more information of whether the B-mode signal comes from galactic and extragalactic dust or from gravitational waves created in the universe's first second.



4 Distant galaxies measured to a precision of 1 percent

When the universe began some 13.8 billion years ago, it held the building blocks of today's cosmic structures. Everything we can see — stars, gas clouds, planets — are made of atoms, which are themselves made of electrons, neutrons, and protons. (Physicists call the latter two "baryons.") In studying the distribution of galaxies across the cosmos in a pattern implanted in the universe's first few hundred thousand years, astronomers have measured the distances to about 1 million distant galaxies with accuracies within 1 percent.

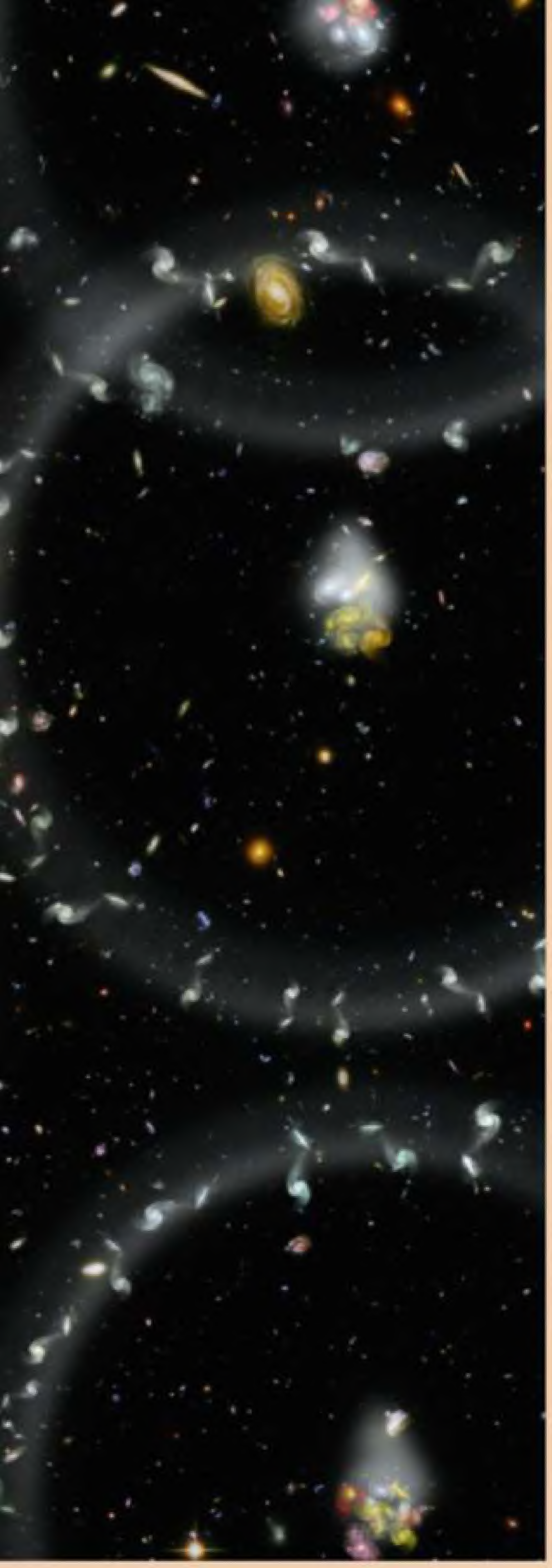
The early universe was a soupy mix of baryons, electrons, photons, and dark matter (a mysterious invisible material). All these particles bounced off one another, making the cosmos an opaque mix. The concoction sloshed around slowly, like a wave in a pool of molasses. This movement set up three-dimensional pressure oscillations similar to spherical-shell sound waves in the material.

Then 380,000 years after the universe's birth, expansion had cooled the cosmos enough for protons to grab onto electrons, forming immense amounts of hydrogen. After that, few individual electrons existed, so photons were free to travel through the cosmos mostly unimpeded.

While the radiation's escape smeared the remnants of the early pressure, or acoustic, oscillations, the distribution of baryonic material kept a record of those waves. Astronomers now see these "baryon acoustic oscillations" (BAOs) across the cosmos, as galaxies tend to cluster along the edges of those shells. The BAOs grew as the universe expanded, and they're now about 500 million light-years in radius. This consistency gives astronomers a ruler to measure distances throughout the cosmos.

Using the Baryon Oscillation Spectroscopic Survey (BOSS), a project of the 14-years-and-counting Sloan Digital Sky Survey, astronomers studied nearly 1 million galaxies across a volume of space 13 billion by 13 billion by 13 billion light-years. Using their BAO ruler, the scientists determined the distances to those galaxies more precisely than any group had measured before: to an accuracy of 1 percent. That's like calculating the distance from Dallas to Austin, Texas — about 200 miles (300 kilometers) — to an accuracy of 2 miles (3km). Except the galaxies the BOSS team studied lie halfway across the universe from us, not a few roadside attractions away.

When astronomers observe galaxies at different distances from Earth, they're really looking at how those objects appeared at different times in the universe's history. The BOSS team used their precise distance calculations to find that when the cosmos was about 3 billion years old, two galaxies separated by 3.3 million

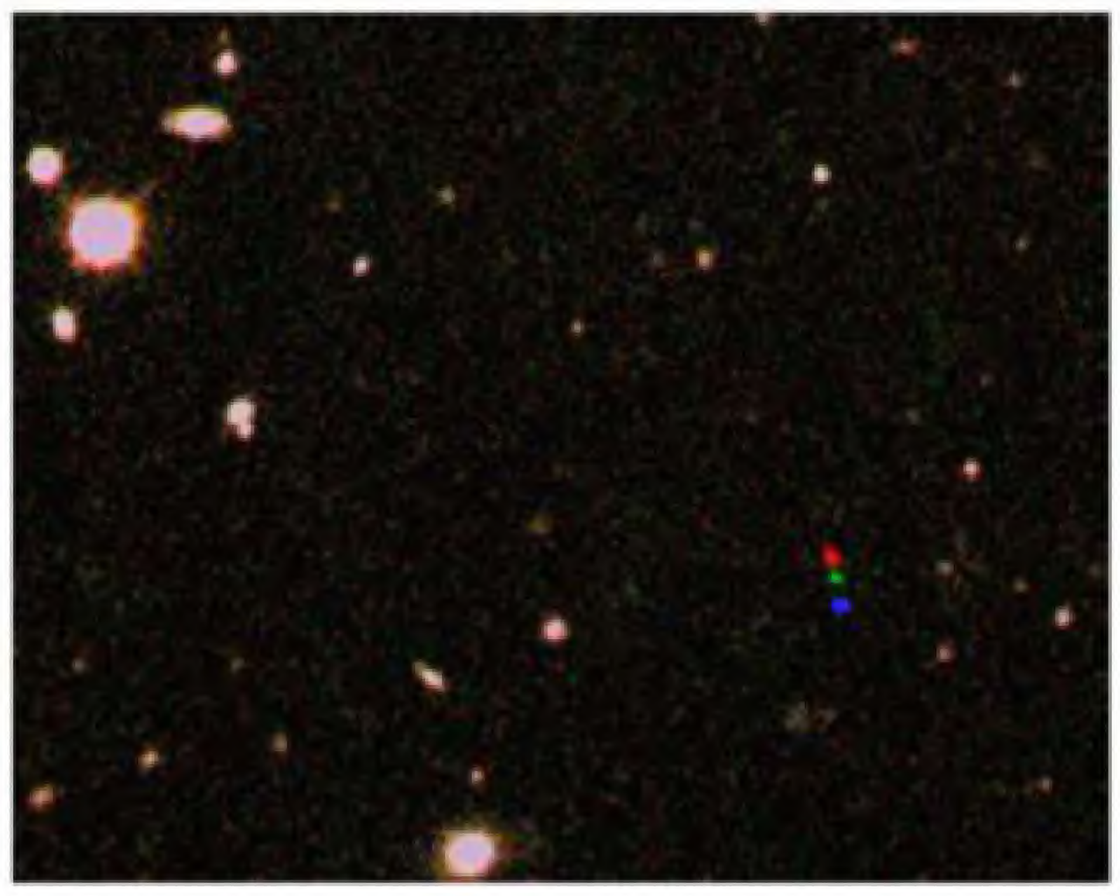


Astronomers studied patterns of galaxies that tend to cluster along the edges of spherical shells, which are remnants of pressure waves from the early universe. By studying this distance ruler, where the white line in this illustration measures about 500 million light-years, researchers determined the distances of galaxies across the cosmos within 1 percent. ZOSIA ROSTOMIAN, LAWRENCE BERKELEY NATIONAL LABORATORY

light-years were moving away from each other at a rate of 140 miles (225km) per second.

"Making these measurements at two different distances allows us to see how the expansion of the universe has changed over time," said BOSS member Rita Tojeiro of the University of Portsmouth in a press release. The BOSS findings appeared in multiple papers and conference presentations this past year.

3 Scientists bag a distant solar system body



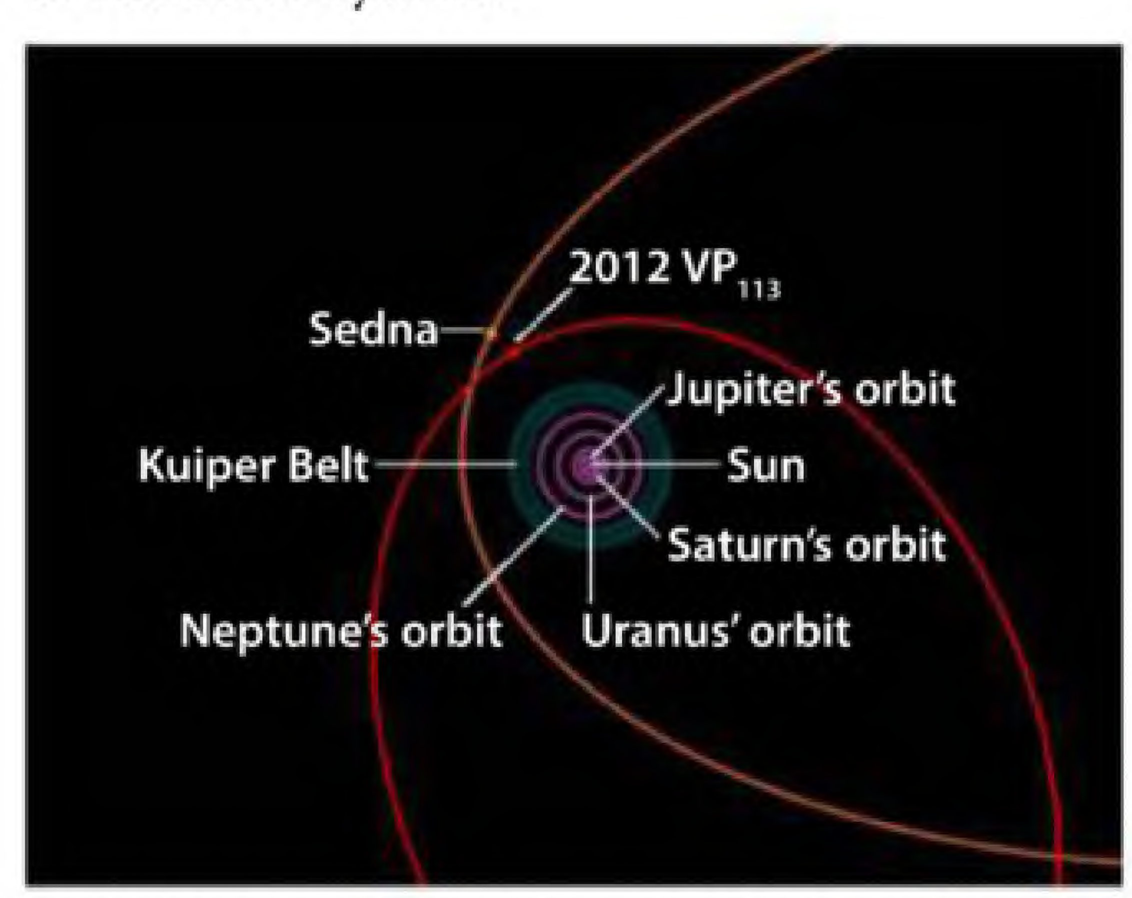
Scientists saw an object move on three images (artificially colored red, green, and blue) taken two hours apart. They've confirmed the body as 2012 VP_{113}, a distant solar system object. SCOTT S. SHEPPARD/CARNEGIE INSTITUTION FOR SCIENCE

When scouring our solar system's plane looking for objects to join the ranks of Pluto and similar dwarf planets, researchers found a possible world. They compared three images each taken two hours apart and found a dot of light that appeared to move. So the scientists, Scott Sheppard of the Carnegie Institution for Science in Washington, D.C., and Chad Trujillo of the Gemini Observatory in Hawaii, used the 6.5-meter Magellan Telescope in Chile to see if that dot on their images was a real object. From these follow-up observations, they determined that the world, now designated 2012 VP_{113}, does, in fact, exist and could be anywhere between 180 miles (300 kilometers) and 420 miles (800km) wide. The scientists announced their solar system find in the March 26 issue of *Nature*.

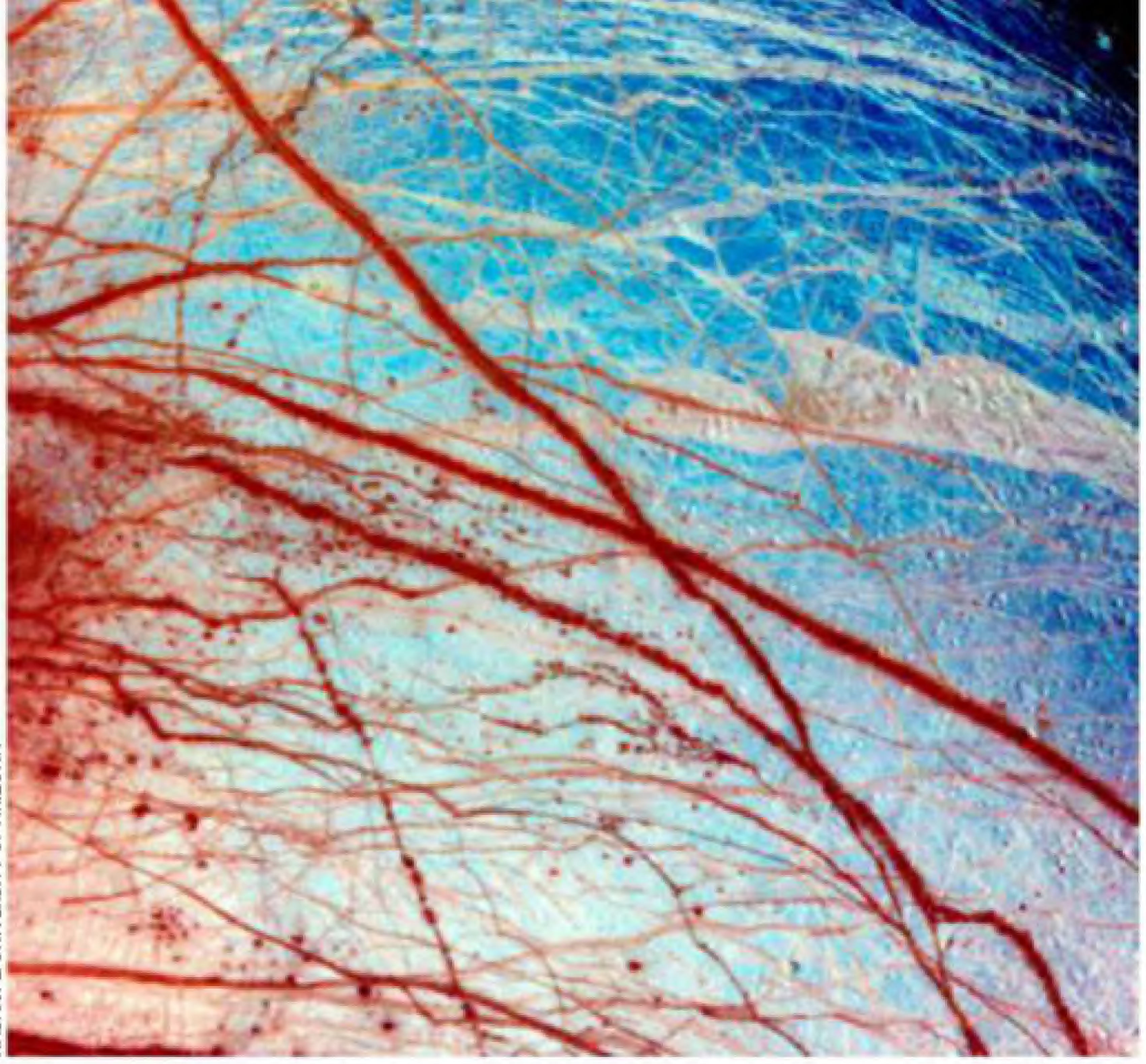
This world reaches its closest point to the Sun, called "perihelion," at about 80 astronomical units (AU, where 1 AU is the average Earth-Sun distance) and travels about 450 AU from our star at its farthest point. This newly found world lies in a similar part of the solar system as an object that scientists discovered in 2003 that goes by the name Sedna, which has a closest approach of about 76 AU and a farthest distance of 1,000 AU. Both objects lie farther from the Sun than the Kuiper Belt, a disk of hundreds of thousands of rocky, icy objects that ranges from 30 AU to about 50 AU from our star; Pluto is the most well-known member of this population.

Adding 2012 VP_{113} to the mix with Sedna confirms the existence of what scientists call an "inner Oort Cloud." (The better-known Oort Cloud is a spherical volume extending from 2,000 AU to 80,000 AU, where the Sun's gravity can just barely hold on to small snowballs; many comets come from the outermost portion.)

Sheppard and Trujillo also noticed orbital similarities among 2012 VP_{113}, Sedna, and the 10 most distant Kuiper Belt objects. They found that all 12 have similar "arguments of perihelion," which is the angle between their nearest points to the Sun and the solar system's plane. "You'd expect them to be completely random," says Sheppard. "One way to explain that is to say that there's a massive object out there shepherding these objects." However, it will take a future observatory, like the 8.4-meter Large Synoptic Survey Telescope, set to come online in the early 2020s, to have any chance of detecting a possible massive object in the outer regions of the solar system.



Both the trans-Neptunian object Sedna and newly discovered 2012 VP_{113} lie far beyond the solar system's major bodies and the Kuiper Belt. SCOTT S. SHEPPARD/CARNEGIE INSTITUTION FOR SCIENCE



NASA/JPL/UNIVERSITY OF ARIZONA

2 Europa has plate tectonics

While studying images of Europa's surface (like the one at left), scientists discovered evidence of plate tectonics on the jovian moon. On this world, the activity involves subduction, where one plate is forced under another, as illustrated below. This process creates low-relief subsumption bands on Europa's surface.

A new analysis from this past year gives more evidence of why scientists should construct a dedicated mission to explore Jupiter's moon Europa. According to a paper published online September 7 in *Nature Geoscience*, the satellite has active plate tectonics, making it the only body in the solar system other than Earth known to host such geological activity.

Astronomers have studied cracks and craters on the moon's icy surface to determine it is likely younger than 90 million years. That young age, compared to the solar system's estimated age of about 4.6 billion years, means that some process recycles Europa's surface.

Cracks and ridges on the satellite appear to be regions where the surface has split and spread a few miles apart, but scientists doubt the moon has increased in size in the past tens of millions of years. So if a new icy crust is being created, where is the old material going?

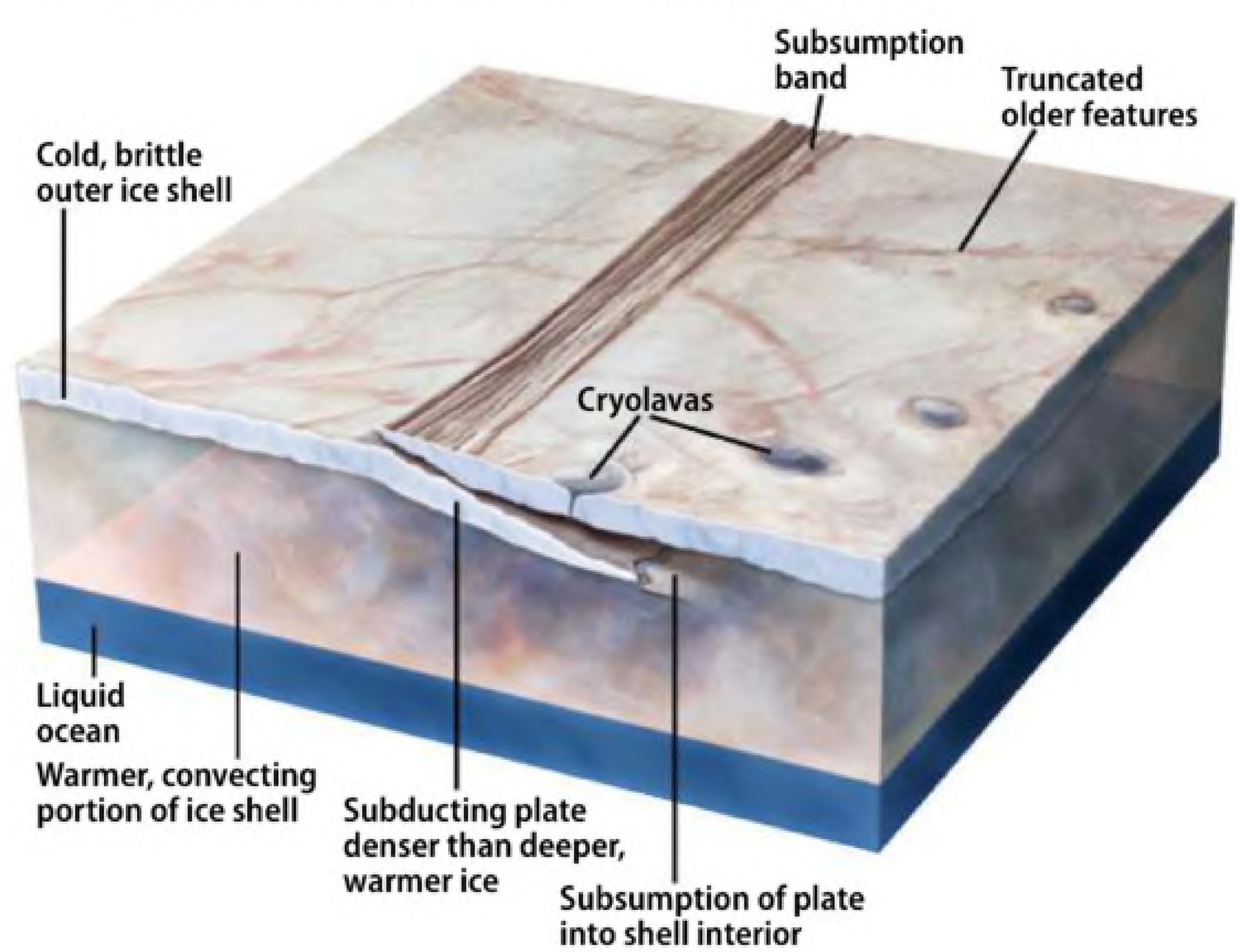
Simon Kattenhorn, formerly of the University of Idaho, and Louise Prockter of Johns Hopkins University analyzed images from NASA's Galileo spacecraft, which visited the jovian system from 1995 to 2003, looking for evidence of plate tectonics on Europa. They found several locations that tantalize of tectonic activity, but in their *Nature Geoscience* paper, they focused on an area covering 52,000 square miles (134,000 square kilometers) in the trailing northern hemisphere.

Kattenhorn and Prockter used Galileo images like a huge jigsaw puzzle to match up different cracks and ridges and reconstruct a model to mimic how the area was arranged millions of years ago. And when they turned the clock back, a region some 62 miles (99km) wide and covering about 8,000 square miles (20,000 square km) seemed to be missing.

Also, some of those cracks and ridges abruptly end. "These truncations suggest that the continuations of these geological features had disappeared into the ice shell because of subduction," says Kattenhorn. Instead of the edges of crustal plates colliding and gathering to create mountain ridges, like the Himalayas on Earth, one of the europan plates is subducting, or moving below an adjacent plate.

In addition to showing that the jovian moon is geologically active, the finding "also implies two-way communication between the exterior and interior — a way to move material from the surface into the ocean — a process which has significant implications for Europa's potential as a habitable world," Kattenhorn said in a press release.

While the September paper provides the strongest evidence yet of active plate tectonics on Europa, confirmation that the material moved downward below the ice shell requires a future mission to the moon. This would, says Kattenhorn, "allow us to obtain better-resolution images of the features we describe in our paper, as well as allowing us to search for additional examples to test if this is a global phenomenon." Better measurements of Europa's topography also likely would come from a future mission. And such a project could make great strides in the search for current or past life at this world, which harbors a global ocean below a fragmented and shifting ice shell.



ASTRONOMY: ROEN KELLY, AFTER NASA/NOAH KROESE, I.NK

STORIES TO WATCH FOR IN 2015

- The European Space Agency's Rosetta craft will have set its Philae lander on the surface of Comet 67P/Churyumov-Gerasimenko in November 2014, so watch for plenty of findings in 2015.
- NASA's New Horizons spacecraft will fly by and study Pluto and its largest moon, Charon, on July 14.
- NASA's Dawn spacecraft will arrive at the asteroid Ceres in April.
- The Dark Energy Survey, which is mapping the southern sky with a 570-megapixel camera in Chile, will release the first year of processed data shortly.

X-RAY: NASA/CXC/ROYAL MILITARY COLLEGE OF CANADA/P. CHANDRA, ET AL.; OPTICAL: NASA/STScI

1 Cosmic dust sources revealed

The remains of the once massive star that exploded as Supernova 2010jl are producing large-grain dust at a fast pace. Astronomers expect the remnant will create nearly half of a solar mass of dust within 20 years.

Our solar system, the Milky Way Galaxy, and the universe as a whole contain a lot of dust, but astronomers have long wondered how it forms. Two studies published this past year (one in February and the other in July) provide the strongest evidence yet that the explosive deaths of massive stars, called supernovae, make this material.

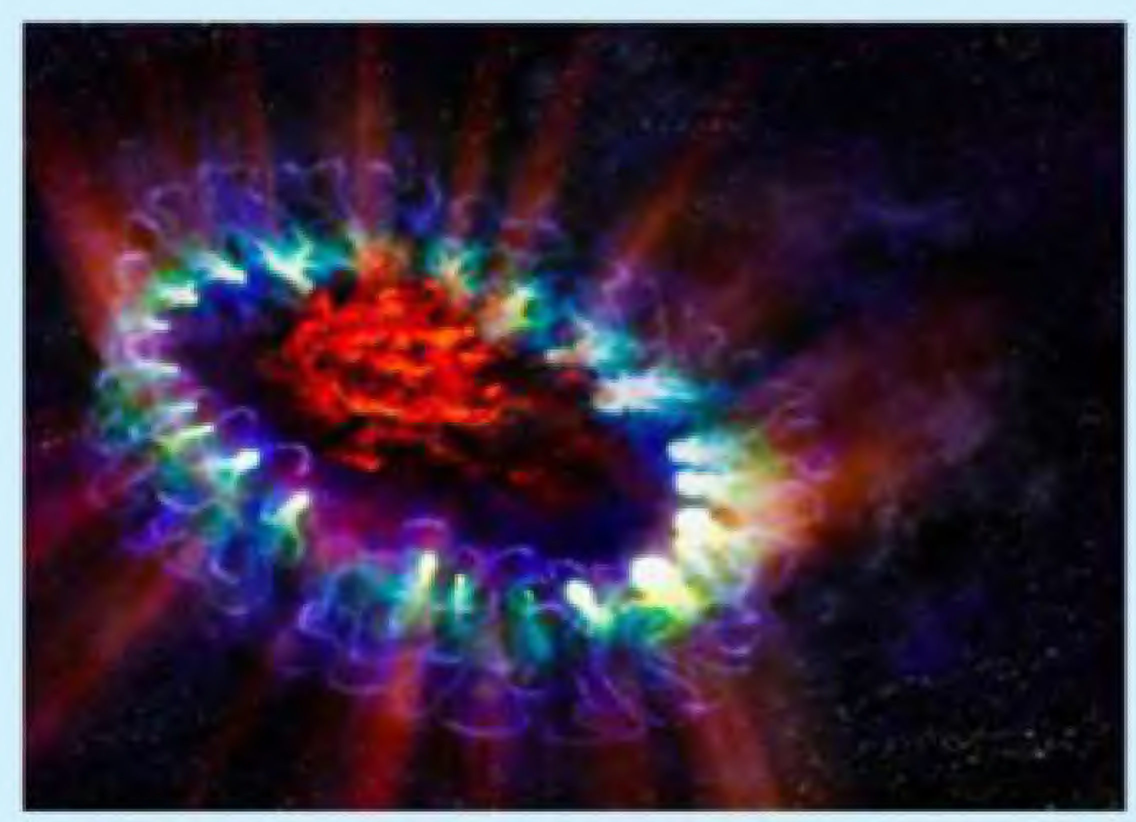
In the first study, scientists used the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile to target Supernova 1987A, whose light first reached Earth in February 1987. This blast marked the death of a star in the Large Magellanic Cloud, a satellite galaxy of our Milky Way. It is the most recent nearby supernova, and thus a fantastic laboratory.

While observations a couple years after the blast measured about a ten-thousandth of the Sun's mass in dust, detections from a few years ago claimed a half to two-thirds of a solar mass of dust. Remy Indebetouw of the University of Virginia in Charlottesville and colleagues decided to revisit the site to measure an accurate value. After fitting the observed radiation to different theoretical light profiles of dust, they found that the inner portions of the supernova's debris hold 0.23 solar mass of dust. Because the material lies at the exact site of the blast, it couldn't have existed before the supernova and thus must have formed as a result of the explosion. But the blast appeared 28 years ago, so the question still remained: How quickly does dust form in a supernova remnant?

While the ALMA observations focused on radio waves and thus cold dust, another team used the Very Large Telescope in Chile to look at a supernova remnant's visible and near-infrared light and therefore hot dust. An object's temperature determines the type of light it gives off. The temperatures studied in these two observations, for comparison, are 26 kelvins (–413° F) versus about 2,000 K (3,000° F).

Christa Gall of Aarhus University in Denmark and colleagues studied Supernova 2010jl, a much more recent blast (and thus much hotter) in the galaxy UGC 5189A. They watched how the amount of dust evolved over the first 2.5 years by observing the site of SN 2010jl nine times between 26 days and 239 days past the explosion's peak brightness and viewed it again 629 days later.

They found much more dust at the site on the last observation than during the nine previous ones, and if the material continues to form at the rate seen, Gall's team expects the supernova remnant will produce about a half of a solar mass of dust after about 20 years. So how did the object create dust? The astronomers think the massive star blew off some material before it exploded, and once the blast happened, a fast-moving shock front slammed into that material and corralled it into a slower-moving, and cooler, shell. There, dust particles could condense.

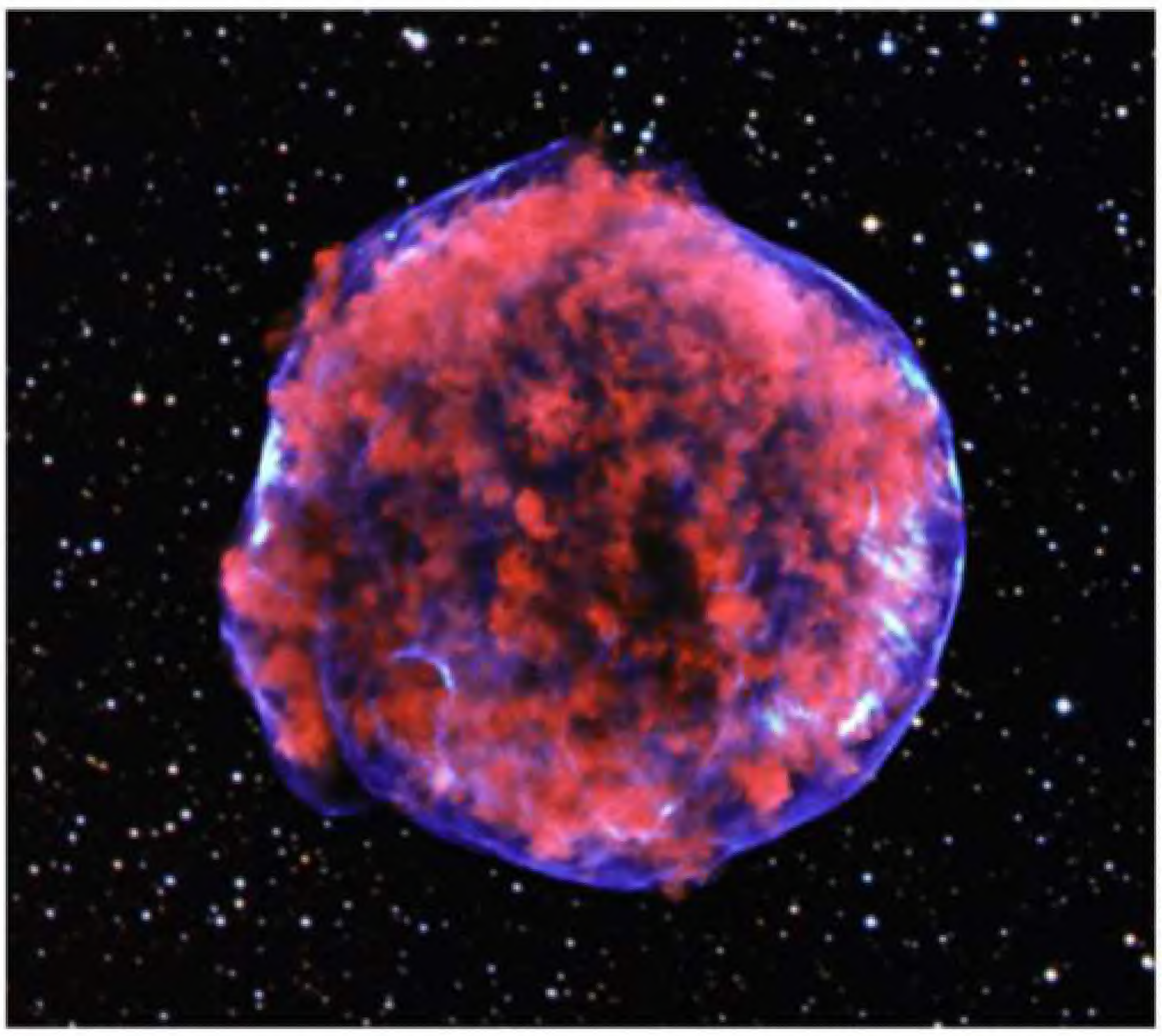


Astronomers spied nearly one-quarter of the Sun's mass in newly created dust at the site of Supernova 1987A, the explosive death of a massive star. The dust is shown in red in this artist's conception. ALEXANDRA ANGELICH (NRAO/AUI/NSF)

Gall's team also compared the strength of the dust's light signal to computer models to get an idea of how big the dust grains are. "The typical grain sizes in the interstellar medium of the Milky Way are much smaller than the grain sizes we found," says Gall. In fact, the dust grains in SN 2010jl are about four times larger than dust seen in our galaxy. The scientists think this large size helps protect the dust from the supernova blast and the ensuing onslaught of extreme temperatures.

LEARN ABOUT 2014'S OTHER BIG STORIES AT www.Astronomy.com/toc.

GLOWING GAS



The expanding gas cloud of Tycho's supernova remnant is heated to millions of degrees, but it's so diffuse that you could fly through it without burning up.

Q: I'VE READ THAT THE GAS EJECTED DURING SUPERNOVA EXPLOSIONS GLOWS AT MILLIONS OF DEGREES; I ALSO HAVE READ THAT GAS IS TENUOUS. HOW WOULD A MILLION-DEGREE GAS FEEL PHYSICALLY? WOULD I VAPORIZE WHILE FLYING THROUGH SUCH A CLOUD?

Raul Pettai, *Montville, New Jersey*

A: The gas, although very hot, is far too tenuous to affect you. Earth's outer atmosphere — hundreds of miles up — rises to 1,800° F (1,000° C) but still won't fry an astronaut on a spacewalk.

The gas density in a supernova remnant is much lower than our outer atmosphere and contains about one particle per cubic centimeter. When the gas is spread over several light-years, its mass can be several times greater than our Sun and contain a large amount of energy. You are absolutely tiny in comparison.

To work the numbers, let's assume your mass is 150 pounds (70 kilograms), which is roughly 5×10^{27} particles. Spreading all those particles out to a density of one per cubic centimeter would correspond to a sphere with a radius comparable to that of Earth!

Tenuous does mean very tenuous. To heat you up to 1.8 million degrees F (1 million degrees C) — the temperature of the supernova remnant — means that you would have to interact with a similar number of hot particles to what you have in your body.

From the above estimate, this means an Earth-radius amount of the tenuous gas. To figure out how far you'd have to fly to hit that many particles, we need to rework the volume from a sphere into a cylinder of the same volume, but with your cross-section area, which I'll assume is a square meter. The length of the cylinder is then about 600,000 light-years, or six times the diameter of our galaxy. That's much, much larger than the supernova remnant.

Just flying through the supernova remnant, you would only gain about 50° F (10° C) from the thermal energy of the hot gas. Your own motion colliding with the hot gas would cause far more drastic effects since you would need to be going very fast, even near the speed of light, if you wanted to go anywhere in your lifetime! Moreover, supernova remnants are accelerators of highly energetic particles known as cosmic rays, and they would be my most serious concern.

Andy Fabian
University of Cambridge, England

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Q: HOW DOES NASA NAVIGATE A MARS ROVER'S DIRECTION AND DETERMINE ITS LOCATION WITH THE PLANET HAVING NO GLOBAL MAGNETIC FIELD?

Norm Cappellina
Phoenix

A: To steer a rover, we need a good base map. The Mariner 9 orbiter expanded maps to cover the Red Planet in the early 1970s. The imaging has only gotten better since then. Depending on where you are, the global map has a resolution anywhere from less than a meter to more than 100 meters. For the Mars Science Laboratory (aka Curiosity), we collected high-resolution images from orbit covering the landing and main science areas on lower Aeolis Mons. NASA and Jet Propulsion Laboratory engineers used this base map and mathematical techniques to point the rover on its way to Mars and land it within a few kilometers of the target. Descent imaging pinpointed the rover within a meter or two on the surface.

For driving, Curiosity takes a series of stereo images around the rover with its navigational cameras (NAVCAM) when it finishes moving for the day. The rover team makes a mosaic from the overlapping images and projects it onto the ground. We then compare this ground-projected image, called an orthophoto, with the base map. We look for similar rocks and ridges in each image and adjust the rover center to a point where the features overlap. The science team locates all other features, like rocks or outcrops that they're interested in, relative to this fixed position. We can calculate these features' positions down to the accuracy of the NAVCAM images, which can reach millimeter precision within a few meters of the rover.

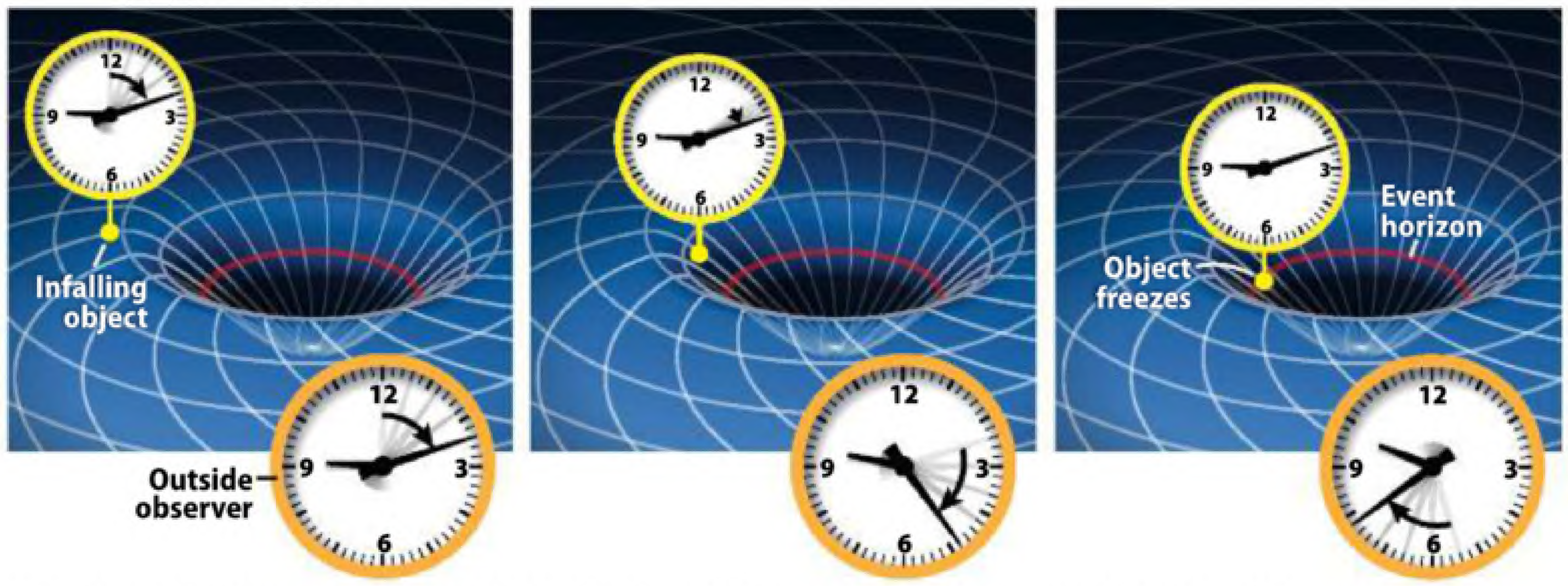
Curiosity also carries an inertial measurement unit (IMU) that gives positional information to help locate the rover, both distance traveled and roll, pitch, and yaw just like an airplane. However, we use "ground in the loop," i.e. humans, to verify and correct errors in drive position after long drives or in cases where we have lots of slip due to sand or skid from steep slopes. While we have many

sophisticated instruments aboard the rover, visual triangulation serves us well to keep the rover on the "straight and narrow" as we head toward our science destinations.

Fred Calef
NASA Jet Propulsion Laboratory
Pasadena, California

Q: WHAT EFFECT DOES TIME DILATION HAVE ON SOMETHING TRYING TO CROSS A BLACK HOLE'S EVENT HORIZON? WOULD THAT MATERIAL CROSS, OR WOULD TIME ESSENTIALLY "FREEZE"? **Jack Kessler**, *El Cerrito, California*

Stopping the clock



A clock crossing the event horizon of a black hole would appear to stop from an outside point of view. Meanwhile, from its own perspective, a clock crossing the event horizon would continue as normal. *ASTRONOMY*: ROEN KELLY

A: An object crossing a black hole's event horizon, the point of no return, will simply pass through from its own perspective, unaffected by time dilation. However, its appearance to outside observers is strongly affected by the black hole's presence. Light signals sent from the object at even time intervals (from the object's perspective) will be received further and further apart in time as the object approaches the event horizon. The strong gravitational field near the event horizon curves space, increasing the distance light must travel to reach the observer. The curvature and distance to the observer — and hence the signal's travel time — approach infinity at the event horizon, so an outside observer will never see an object actually fall into a black hole. The object instead will appear to freeze at the event horizon.

This effect motivated the original name of "frozen stars" for the object left behind after the total collapse of a massive star. Astronomers thought that light from the last parts of the star to collapse would forever be seen emanating from just outside the newly formed event horizon. The term *black hole* came from the recognition that the wavelength of light is also stretched near the event horizon. The light coming from close to the event horizon becomes so stretched ("redshifted") that it is rendered unobservable. So, while material does appear to freeze as it approaches an event horizon, it simultaneously disappears. A collapsed star should rapidly fade from view, and what's left behind is appropriately called a black hole.

Jason Dexter
Max Planck Institute
Garching, Germany

Q: WHAT IMPACT HAS THE KEPLER SPACE TELESCOPE'S EXOPLANET DISCOVERIES HAD ON THE DRAKE EQUATION?

Jeff Fleenor, *Pella, Iowa*

$$N = N_s \times F_p \times F_l \times F_i \times L_c/L_s$$

N is the number of civilizations in the Milky Way today.

N_s is the number of stars in the Milky Way.

F_p is the fraction of stars with habitable planets.

F_l is the fraction of habitable planets with life.

F_i is the fraction of life-bearing planets where intelligent civilizations arise.

L_c is the typical lifetime of a civilization in years.

L_s is the typical lifetime of a star (10 billion years for Sun-like stars).

A: For millennia, we humans have looked up at the night sky and wondered if, out there, there are other worlds like our own, and if, on some of those worlds, there are other beings that wonder as we do.

One tool to address this question is the Drake equation, which lays out the quantities needed to estimate the number of intelligent civilizations in the Milky Way Galaxy. I'll define an intelligent civilization as one capable of communicating over interstellar distances. Our species has had this capability for less than a century.

NASA's Kepler space telescope has completely altered our view of planets beyond the solar system. The mission has shown, among other things, that as many as one in five Sun-like stars harbors an Earth-sized planet residing in the "habitable zone," the range of orbital distances where liquid surface water could plausibly exist. There are roughly 200 billion stars in the Milky Way Galaxy, of which a quarter are Sun-like. So there are about 10 billion potentially habitable planets around Sun-like stars in the Milky Way alone. Prior to Kepler, F_p was entirely unconstrained. With Kepler, astronomers have measured F_p, at least roughly. Uncertainties remain for several reasons: The boundaries of the habitable zone are uncertain, Kepler has only probed a narrow slice of the galaxy, and there are likely other necessary conditions for life besides surface liquid water. I am hopeful that, in my lifetime, we will launch telescopes capable of imaging distant Earth-like worlds and "sniffing" their atmospheres to look for signs of alien life.

Erik Petigura
University of California, Berkeley

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

January 2015: Jupiter's marvelous moons

The shadows of three moons crossed Jupiter's disk October 11/12, 2013. In this time sequence, which runs left to right, Callisto's shadow appeared farthest south (bottom) and led the way, followed by Europa's and then Io's. Io (top) and Europa lie just off Jupiter's eastern (left) limb. LEO AERTS

The new year begins with Mercury and Venus together in evening twilight. Although the two inner planets look great, the night sky's true star is Jupiter. The giant world dominates from midevening through dawn, and observers who target it through a telescope will get great views of its dynamic atmosphere and four bright moons. You won't want to miss the events the night of January 23/24, when the shadows of three moons simultaneously appear against Jupiter's cloud tops followed less than a half-hour later by the same moons' disks. Finally, as Jupiter wheels into the western sky before dawn, Saturn becomes prominent in the southeast.

Our tour of January's night sky begins low in the southwest after sunset. **Venus** and **Mercury** spend the month's first three weeks within the field of view of 7x50 binoculars. Venus shines brilliantly at magnitude –3.9 and shows up easily in bright twilight; it serves as a guide for finding Mercury during this period.

On January 1, Mercury lies 3° to Venus' lower right and some 4° above the horizon 30 minutes after sunset for people at mid-northern latitudes. The innermost planet glows at magnitude –0.8, just 6 percent as bright as its neighbor but still good enough to show up in twilight.

By January 10, Mercury's altitude a half-hour after sundown has more than doubled (to 9°), and it appears conspicuous only 0.6° due west of Venus. This marks their closest approach of 2015, though the two technically don't experience a conjunction because they never have the same right ascension. The planets remain within 1° of each other through the 13th.

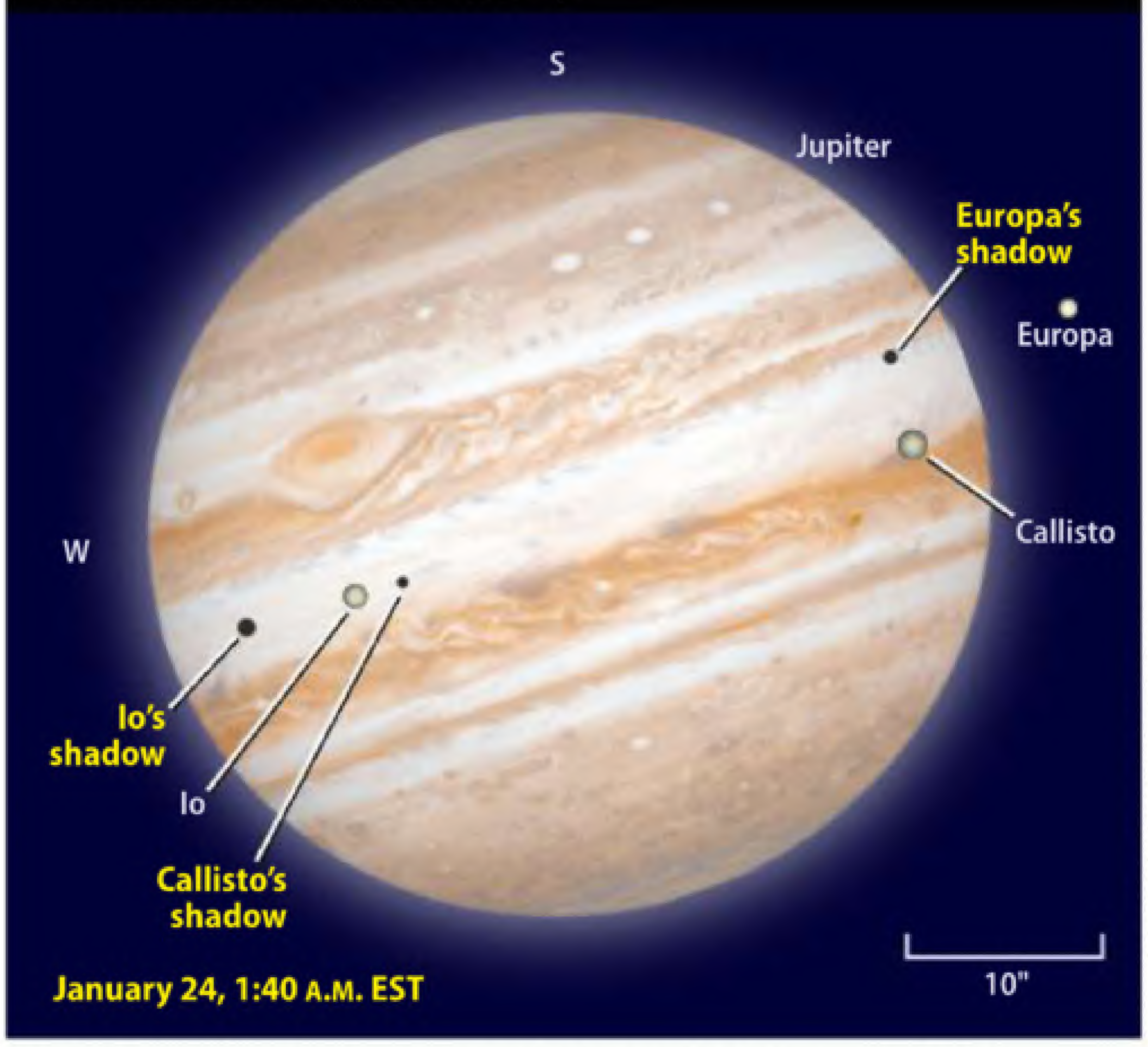
As Mercury swings away from Venus, the innermost planet reaches greatest elongation January 14. It then lies 19° east of the Sun and hangs 10° above the horizon a half-hour after sunset. The planet remains bright (magnitude –0.7) and distinct in twilight. A few days after greatest elongation, Mercury starts to fade and sink lower, and it passes between the Sun and Earth on the 30th. But it has one last hurrah before departing. As darkness falls January 21, the waxing crescent Moon stands 5.5° above Mercury (now at magnitude 0.6) and the same distance to Venus' right.

View Mercury through a telescope this month, and you'll see quick changes. On the 1st, its disk spans 5" and appears nearly full. At greatest elongation on the 14th, the planet shows a 7"-diameter disk that's slightly more than half-lit. And by the time of its conjunction with the Moon on the 21st, it appears 9" across and just one-quarter lit. Venus, on the other hand, varies little this month, with its disk growing from 10" to 11" and its phase shrinking from 96 percent to 92 percent lit.

As twilight deepens, a distinctly orange-colored point of light appears above Mercury and Venus. You can't miss **Mars** — at magnitude 1.1, it shines brighter than any nearby star. The Red Planet

*Martin Ratcliffe provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist **Alister Ling** works for Environment Canada in Edmonton, Alberta.*

Galilean satellites triple the fun



On the night of January 23/24, the shadows of Io, Callisto, and Europa simultaneously cross Jupiter. Shortly after, the moons themselves follow.

ALL ILLUSTRATIONS: ASTRONOMY: ROEN KELLY

RISING**MOON**

A dark spot on the Full Moon's brilliance

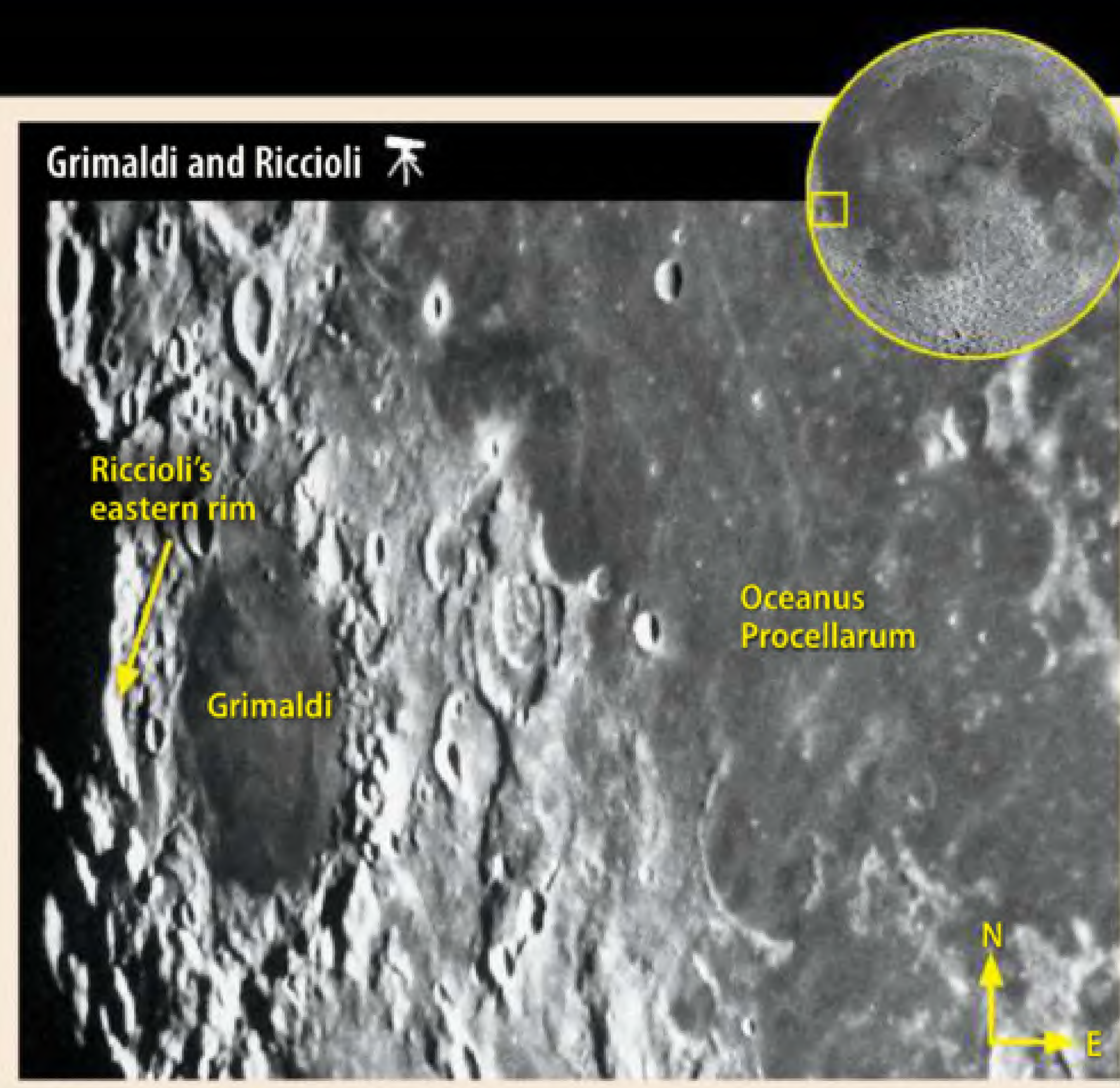
The large impact crater Grimaldi stands out as a dark lava-filled basin near the Moon's western limb just beyond the edge of the giant mare known as Oceanus Procellarum (Ocean of Storms). The first rays of sunlight spread over Grimaldi the evening of January 3.

The crater's highly battered rim appears quite ragged thanks to the pummeling it received over many eons by smaller projectiles. Although the rim doesn't rise far above its surroundings, the low Sun angle causes it to cast long shadows onto the crater's smooth floor. At Full Moon the next evening (January 4), these shadows have completely disappeared. Many other interesting sights have appeared west of Grimaldi, however, notably the equally large and battered crater Riccioli. This feature's floor appears much rougher than its neighbor's because the lava that flooded Oceanus Procellarum and Grimaldi didn't flow that far.

If you spend some time viewing Grimaldi, you'll notice that the seemingly monotonous gray of its floor is not uniform. Also note a couple of indistinct rays — lighter rock ejected during relatively recent major impacts — in the crater's northern half.

To make viewing the nearly Full Moon easier on your eyes, use a dark filter on the eyepiece to reduce the brightness. Alternatively, you can crank up the telescope's power to capture less surface area.

You can see Grimaldi in a totally different light on the morning of January 17 when the Moon is a gorgeous waning crescent. While earthshine bathes the rest of Luna's face, Grimaldi appears conspicuous as a sharply defined dark ellipse. Notice how much farther from the limb it lies than it did on the 3rd when it was tucked against the edge. This so-called libration, which lets us see a bit onto the Moon's farside, occurs because our satellite's rotation on its axis is slightly out of sync with its orbit around Earth.



The lava-filled crater Grimaldi lurks near the Moon's western limb and comes into view before Full Moon. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

lies 20° high in the southwest an hour after sunset throughout January. A telescopic view proves disappointing, however, because Mars' disk measures less than 5" across and shows no detail.

Mars maintains its altitude because it races eastward in front of the stars of Capricornus and Aquarius at nearly the same rate as the Sun traverses Sagittarius and western Capricornus. The planet's motion carries it just 0.2° south of **Neptune** on January 19. Use a telescope to view the two worlds together and compare Mars' ruddy glow to Neptune's blue-gray hue. Neptune shines at magnitude 7.9 and appears about half of Mars' diameter despite lying some 15 times farther away.

Neptune has a second close encounter this month, though it will be harder to view. On

— Continued on page 42

METEORWATCH

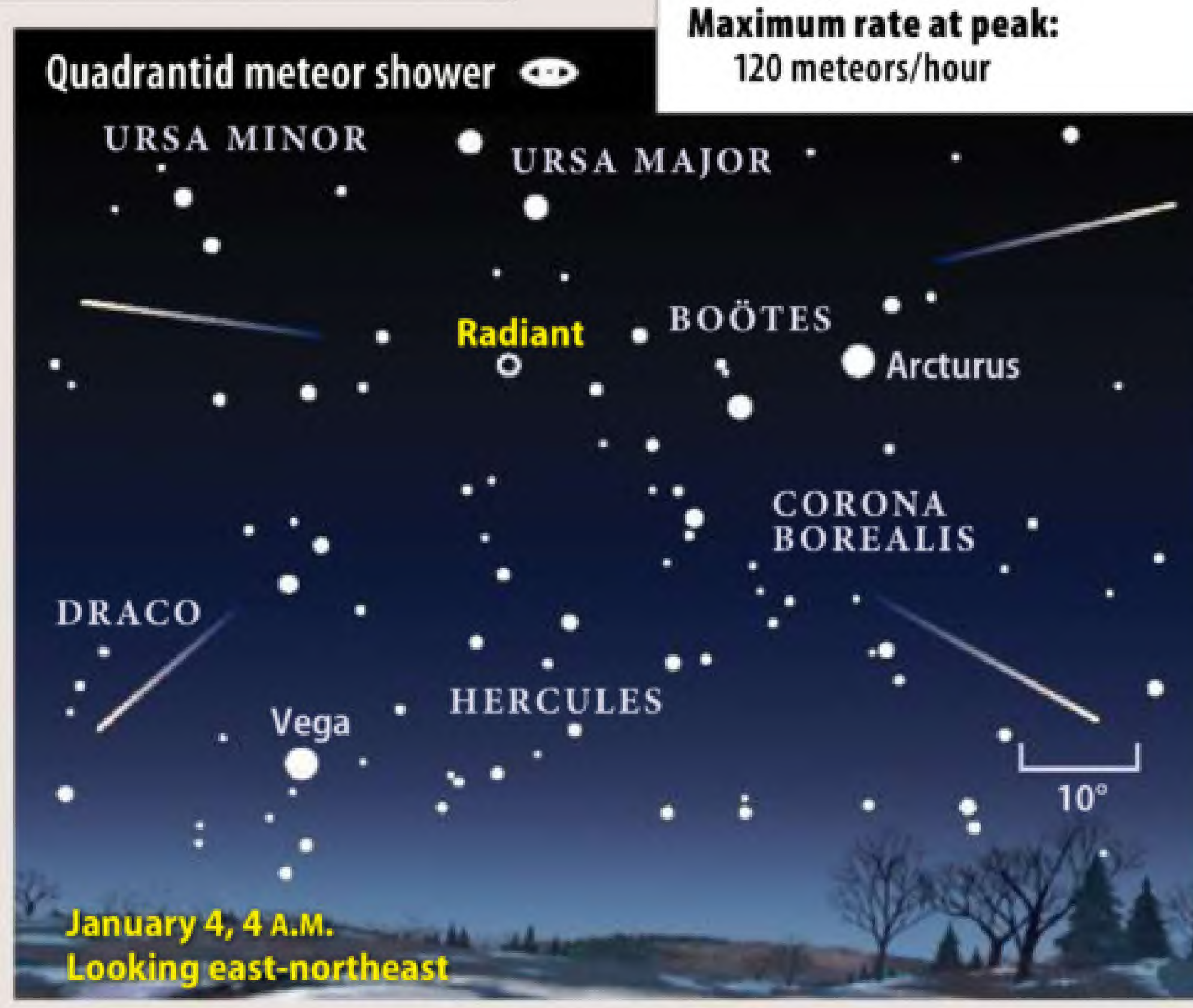
Full Moon headaches for the Quadrantids

Quadrantid meteors

Active Dates: Dec. 28–Jan. 12
Peak: January 3
Moon at peak: Full Moon
Maximum rate at peak: 120 meteors/hour

One of the year's most prolific meteor showers peaks the night of January 3/4. The Quadrantids can produce 120 meteors per hour at their best, but "best" implies viewing under a dark sky with the radiant — the point in northern Boötes from which the meteors appear to originate — nearly overhead. Unfortunately, Full Moon arrives a day after the peak, so dark skies will be impossible to find.

Your best bet is to observe in the hour before dawn breaks. Pick a spot where you can hide the Moon, which hangs low in the west, behind some buildings or trees. The show won't be great, but you still could see a dozen or two meteors per hour.



A nearly Full Moon disrupts the peak of this year's Quadrantid meteor shower, though observers still could see a dozen or two meteors per hour.

OBSERVING HIGHLIGHT The middle two weeks of January provide Northern Hemisphere observers with some of their finest evening views of Mercury this year.

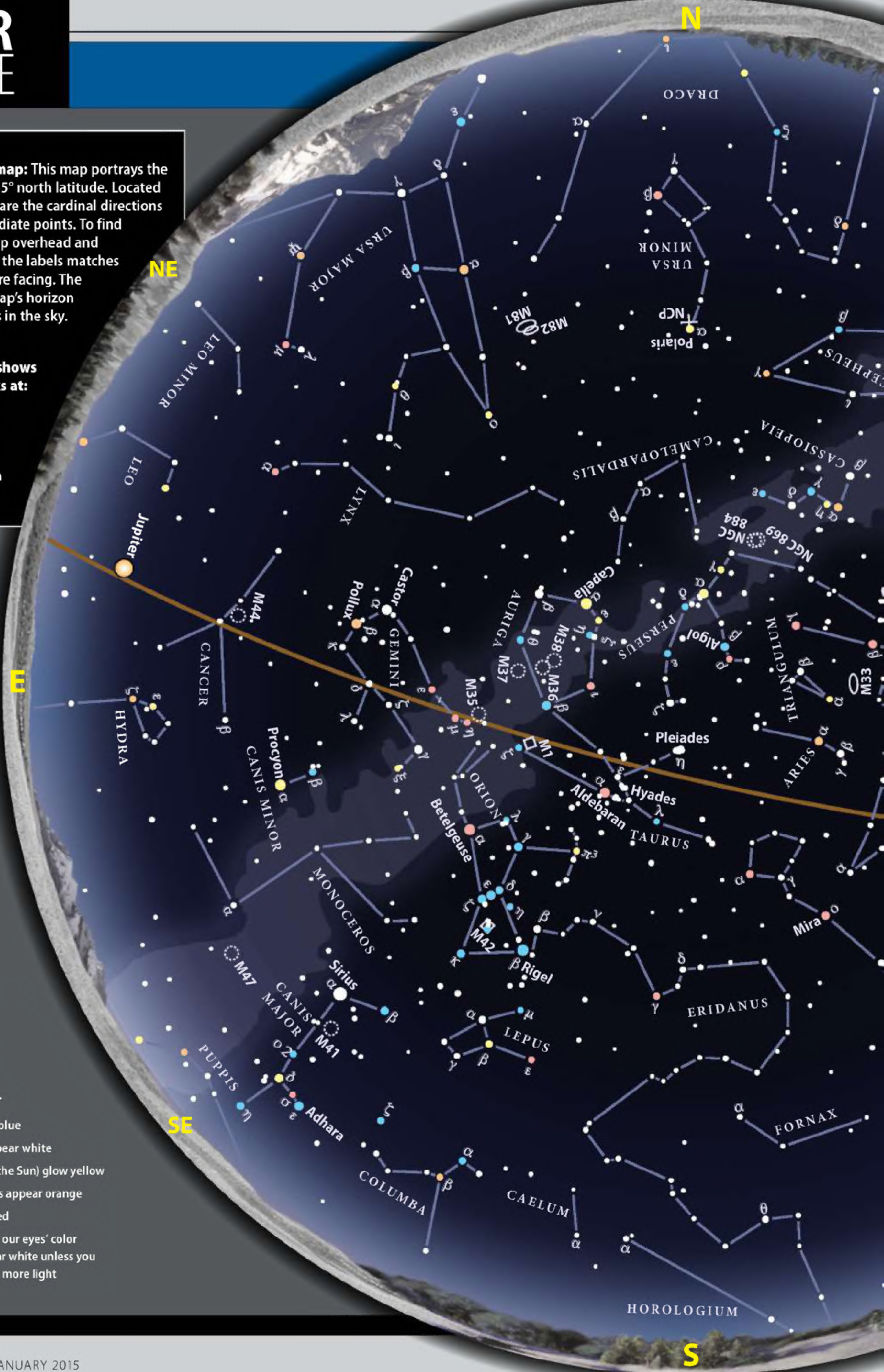
STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. January 1
8 P.M. January 15
7 P.M. January 31

Planets are shown at midmonth



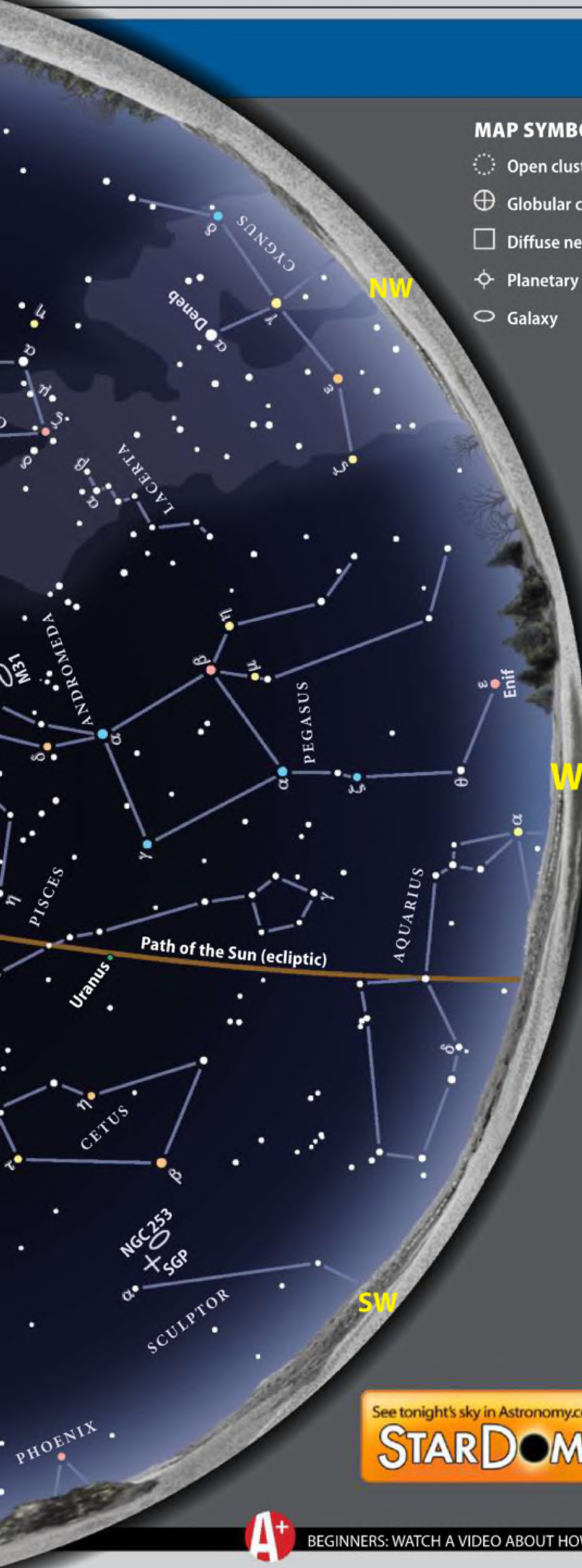
STAR MAGNITUDES

Sirius
0.0
1.0
2.0
3.0
4.0
5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

JANUARY 2015

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

3 Pluto is in conjunction with the Sun, 7 P.M. EST

Quadrantid meteor shower peaks

4 Earth is at perihelion (91.4 million miles from the Sun), 2 A.M. EST

Full Moon occurs at 11:53 P.M. EST

8 The Moon passes 5° south of Jupiter, 3 A.M. EST

9 The Moon is at apogee (251,909 miles from Earth), 1:18 P.M. EST

11 Asteroid Vesta is in conjunction with the Sun, 1 A.M. EST

13 Last Quarter Moon occurs at 4:46 A.M. EST

14 Mercury is at greatest eastern elongation (19°), 3 P.M. EST

16 The Moon passes 1.9° north of Saturn, 7 A.M. EST

19 Mars passes 0.2° south of Neptune, 4 P.M. EST

20 New Moon occurs at 8:14 A.M. EST

Mercury is stationary, 11 P.M. EST

21 The Moon passes 3° north of Mercury, 1 P.M. EST

The Moon is at perigee (223,473 miles from Earth), 3:07 P.M. EST

The Moon passes 6° north of Venus, midnight EST

22 The Moon passes 4° north of Neptune, 8 P.M. EST

The Moon passes 4° north of Mars, midnight EST

SPECIAL OBSERVING DATE

23 Three of Jupiter's moons — Io, Europa, and Callisto — and their shadows transit the planet's disk during an eight-hour period overnight.

25 The Moon passes 0.6° north of Uranus, 7 A.M. EST

26 First Quarter Moon occurs at 11:48 P.M. EST

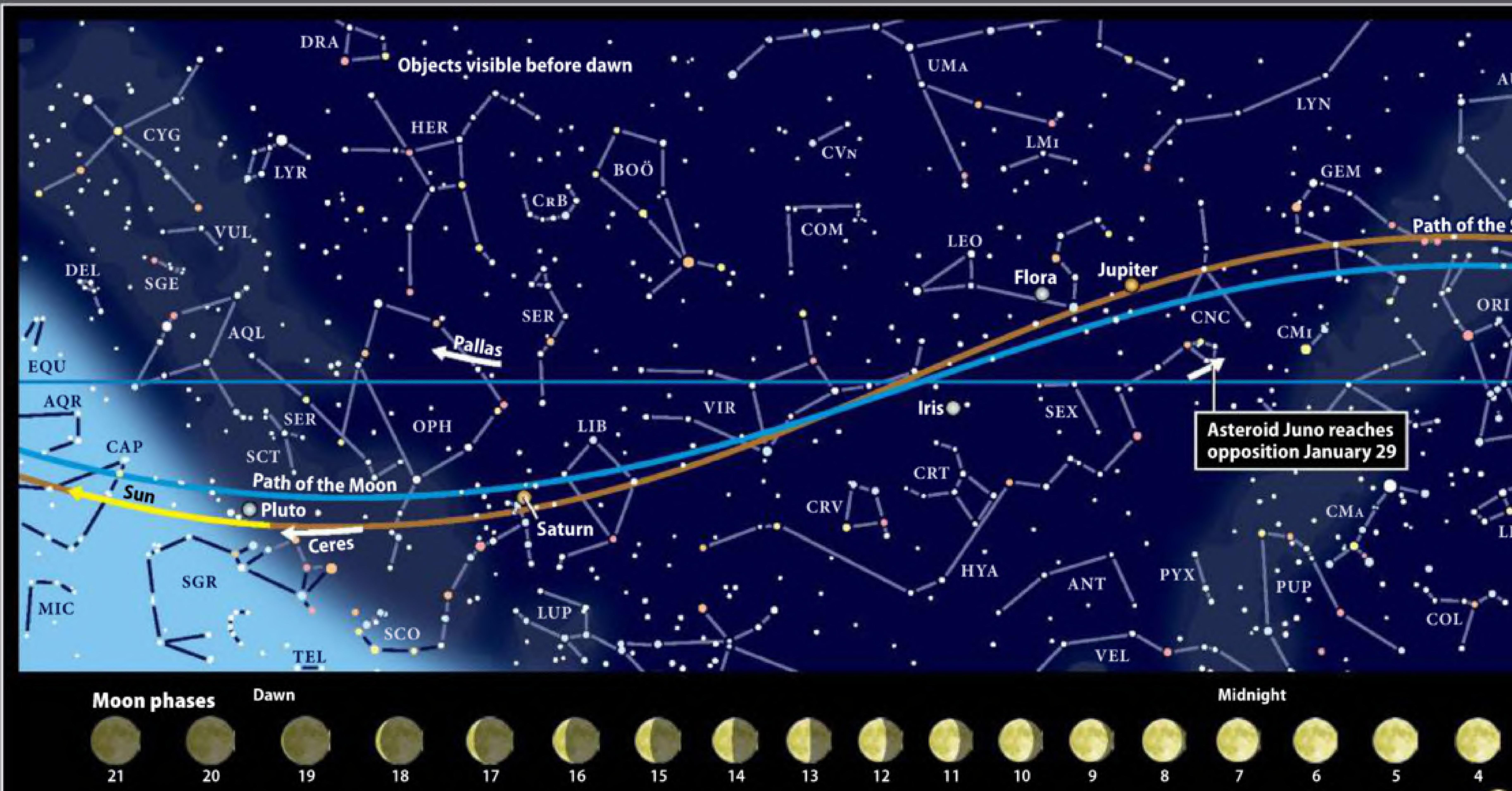
29 The Moon passes 1.2° north of Aldebaran, 1 P.M. EST

Asteroid Juno is at opposition, 6 P.M. EST

30 Mercury is in inferior conjunction, 9 A.M. EST

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

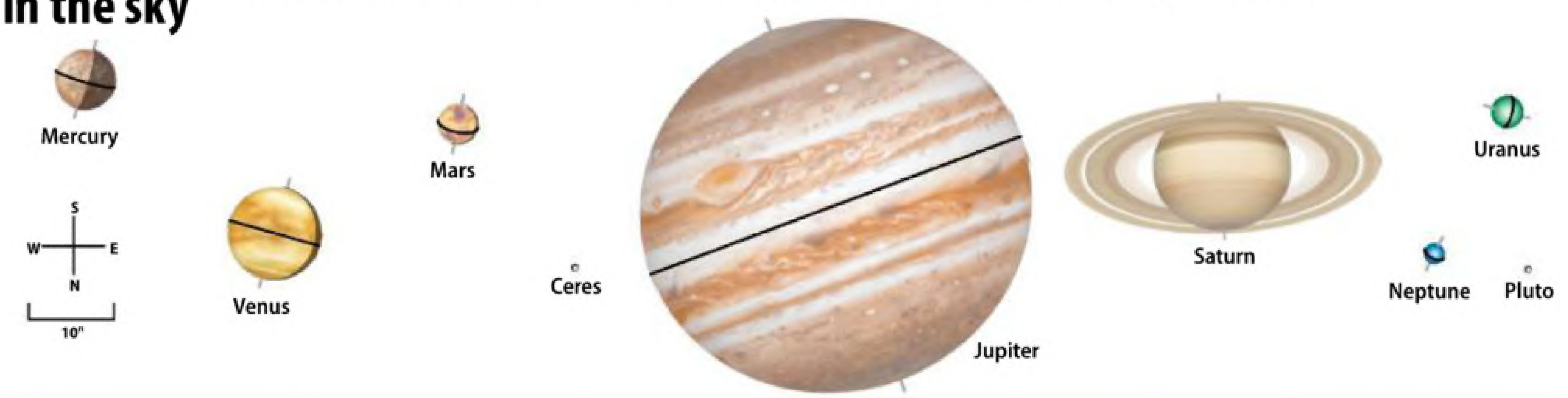
The planets in January 2015



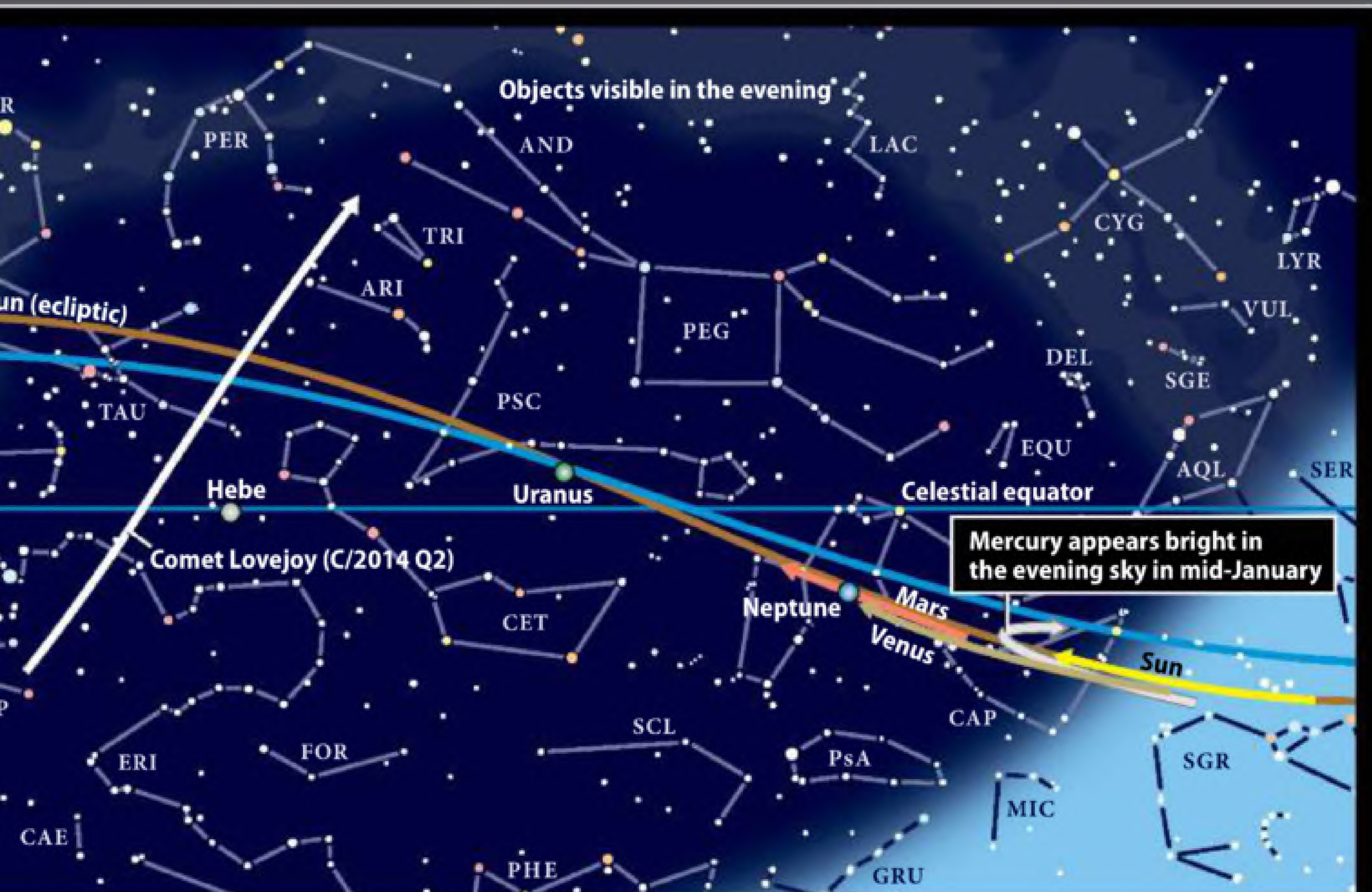
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.

The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



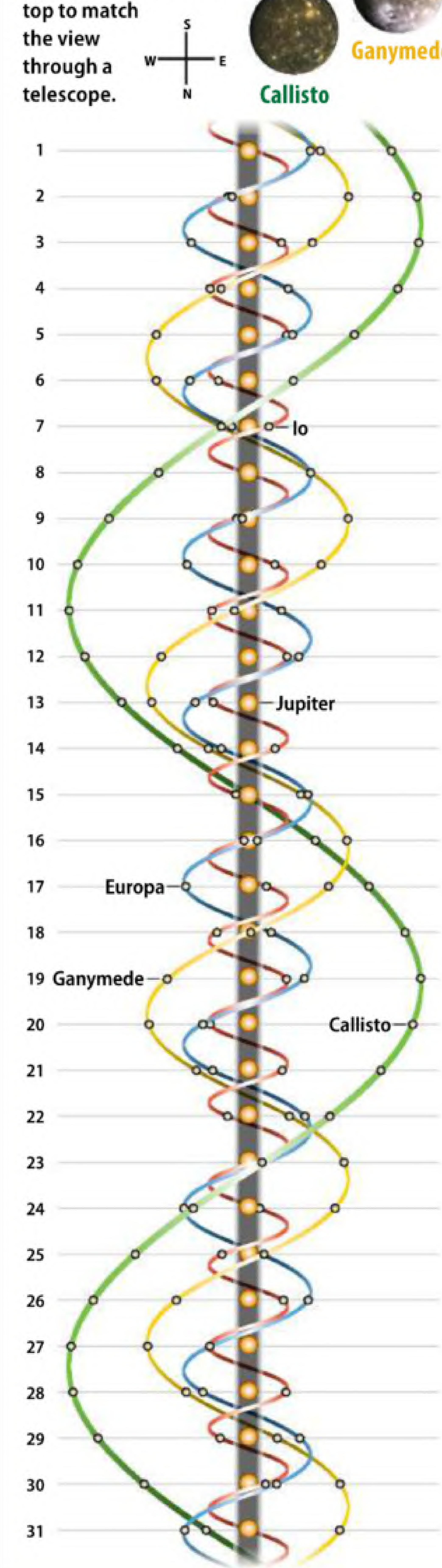
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15
Magnitude	–0.7	–3.9	1.1	9.0	–2.5	0.6	5.8	7.9	14.2
Angular size	6.9"	10.6"	4.6"	0.4"	44.6"	15.8"	3.5"	2.2"	0.1"
Illumination	57%	94%	95%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.974	1.572	2.033	3.721	4.423	10.527	20.181	30.701	33.763
Distance (AU) from Sun	0.322	0.728	1.389	2.832	5.325	9.957	20.005	29.969	32.798
Right ascension (2000.0)	21h03.2m	21h07.9m	22h16.7m	18h10.3m	9h31.8m	16h01.2m	0h47.4m	22h30.6m	18h57.5m
Declination (2000.0)	–17°21'	–18°07'	–11°46'	–24°04'	15°35'	–18°39'	4°23'	–10°09'	–20°38'

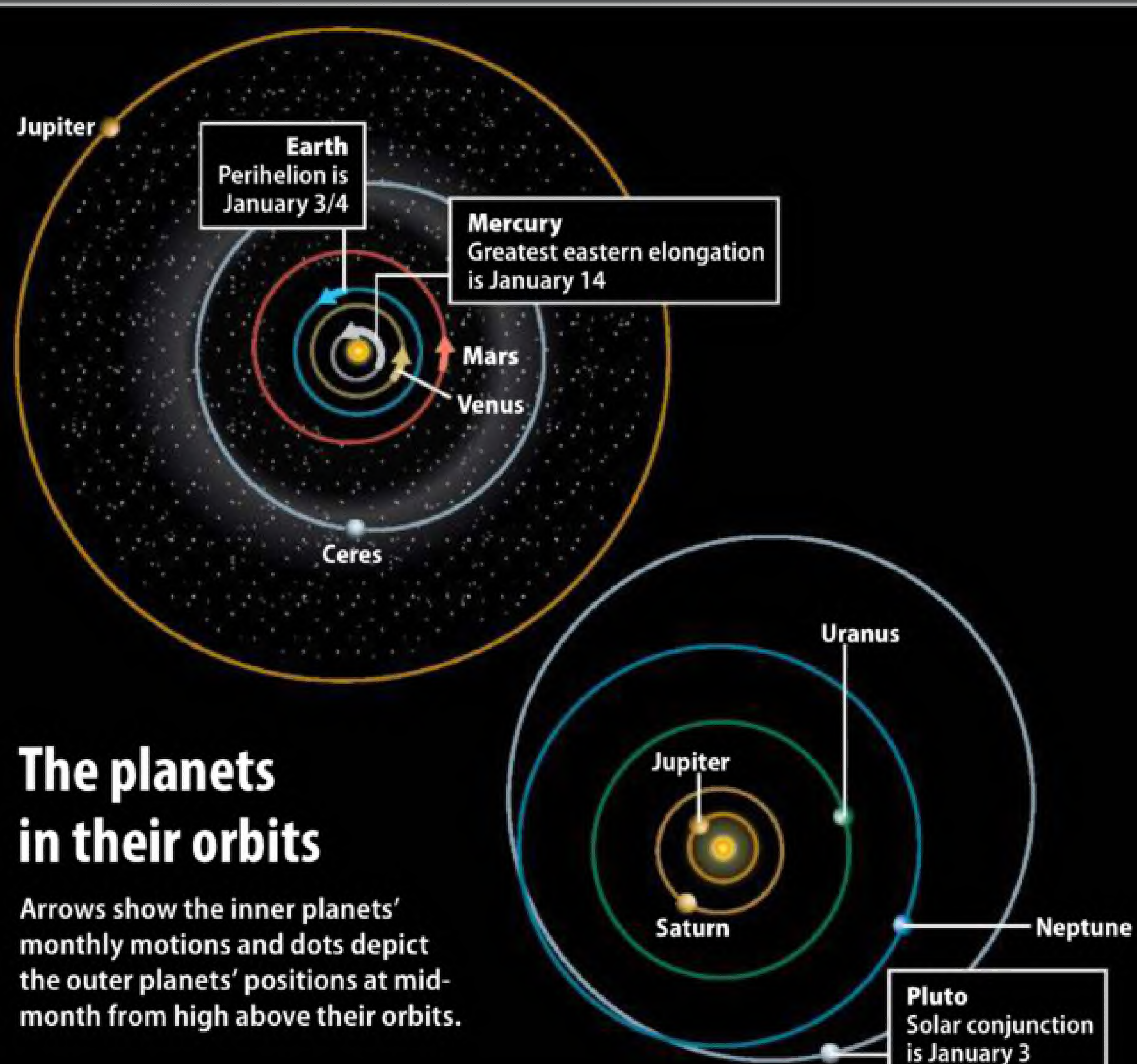


Early evening

Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EST on the date shown. South is at the top to match the view through a telescope.





The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

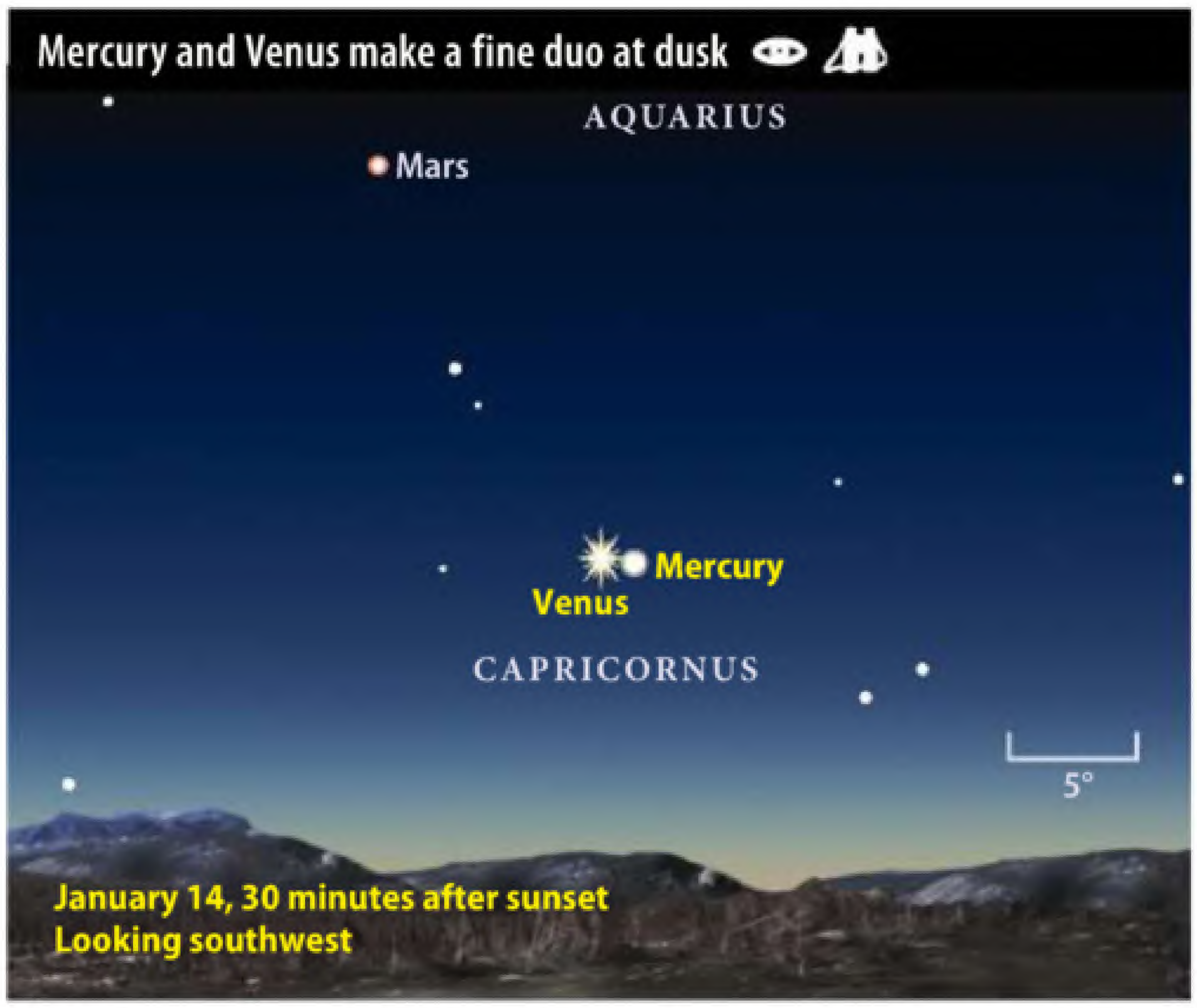
EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)	Jupiter (southeast)	Jupiter (west)
Venus (southwest)		Saturn (southeast)
Mars (southwest)		
Uranus (south)		
Neptune (southwest)		

January 31, Venus approaches within 1.2° of the distant world. The pair stands only 10° high an hour after sunset, however, and it will be difficult to see Neptune against the twilight.

Uranus rides high in the southwest after darkness falls this month. On the 15th, it appears halfway to the zenith at 7 P.M. local time and sets after 11 P.M. The planet glows at magnitude 5.8, so binoculars will let you track it down. Uranus lies in the company of three similarly bright stars 3.2° due south of magnitude 4.4 Delta (δ) Piscium. A telescope will confirm a sighting of the ice giant by revealing its 3.5"-diameter disk and blue-green color.

Brilliant **Jupiter** rises around 8 P.M. local time in early January and some two hours earlier by month's end. It brightens from magnitude –2.4 to –2.6 this month and dominates the night sky from the time it rises until dawn. The giant world resides among the background stars of Leo, to the west-northwest of that constellation's brightest star, 1st-magnitude Regulus. The gap between the two objects grows from 8° to 12° during January.

The Sun's largest planet never disappoints those who view it through a telescope.



The inner two planets appear near each other during the first half of January. You can use brilliant Venus as a guide to its fainter companion.

Jupiter's disk grows from 43.4" to 45.3" across during January, ending the month just 0.1" short of its peak at opposition in early February. The planet's dynamic atmosphere changes appearance hour by hour as its rapid spin carries new details into view.

The most obvious features are two dark belts straddling a brighter zone that coincides with the gas giant's equator. On nights when Earth's atmosphere is steady (you'll know because stars won't twinkle much), a series of dark belts and bright zones comes into view. Also check out the Great Red Spot if it happens to be on the Earth-facing hemisphere. This giant storm has shrunk

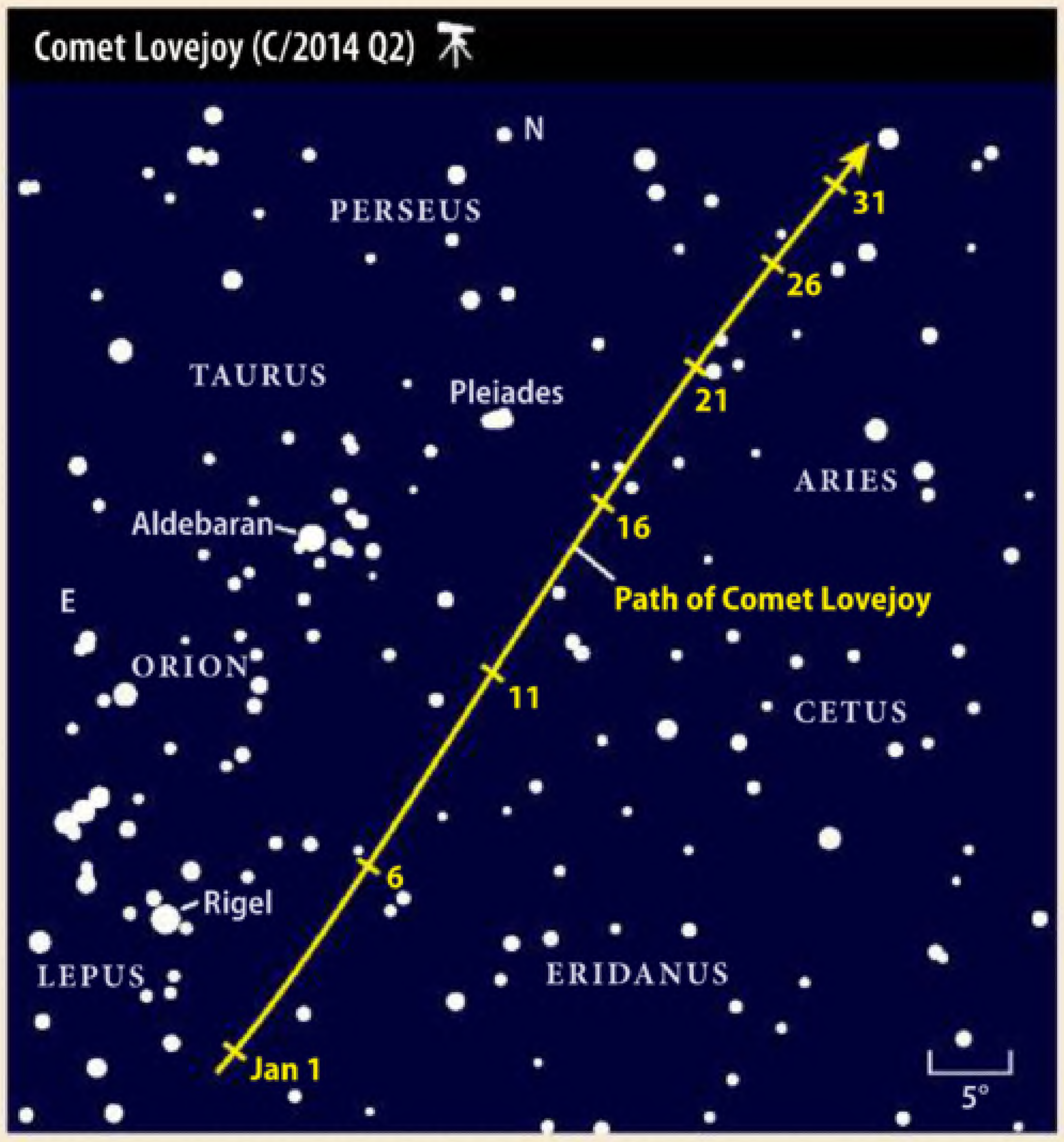
COMETSEARCH

Give a little love to Comet Lovejoy

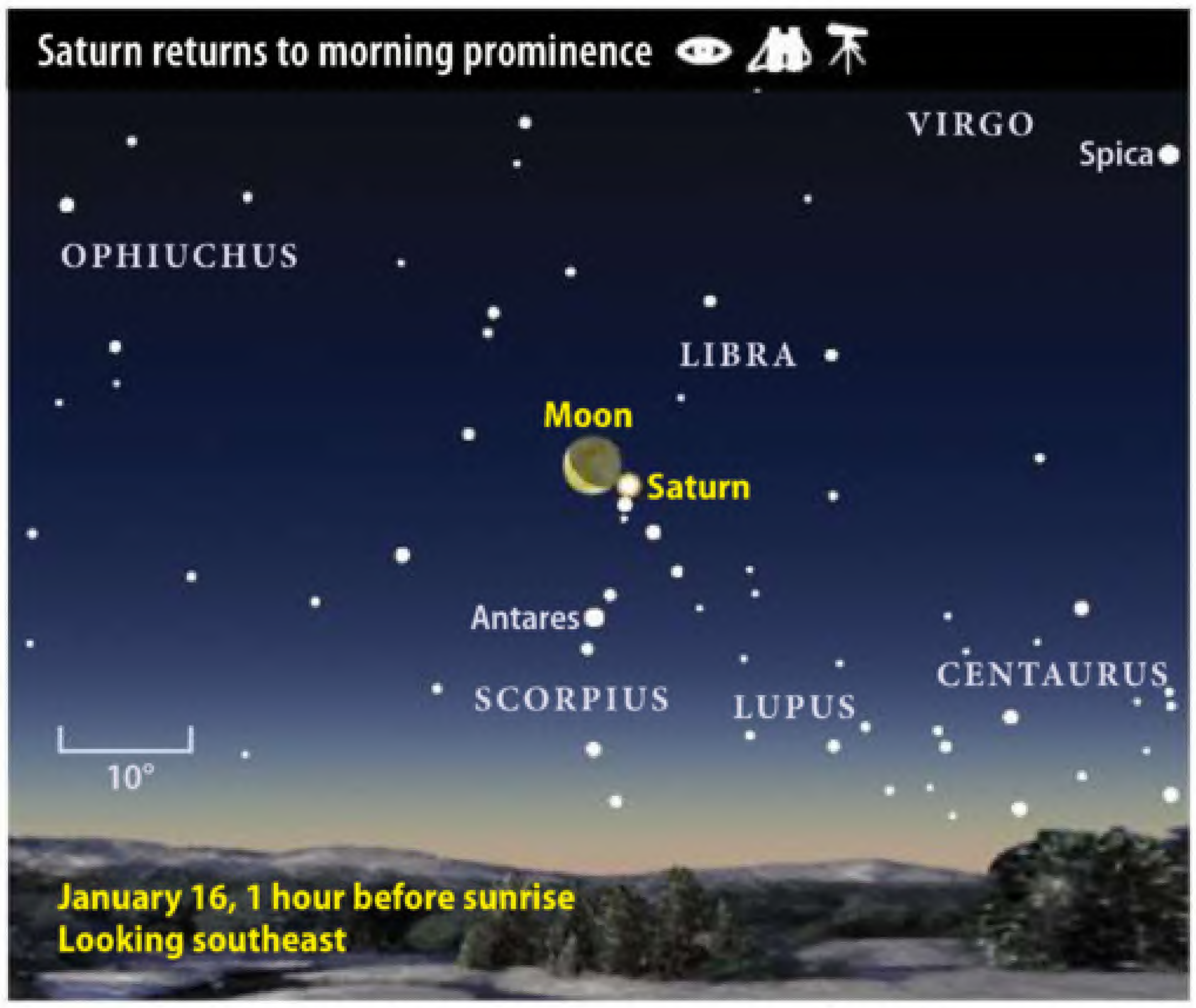
Although spectacular comets have been rare recently, a steady stream of more modest ones has kept our observing juices flowing. Case in point: Comet Lovejoy (C/2014 Q2), which will be nicely placed for evening viewing in January. Lovejoy bolts out from under Lepus the Hare in early January and arrives near the foot of Andromeda the Princess by month's end. Astronomers predict the comet will glow around 8th magnitude, which would make it difficult to spot from a city. If you head to a dark-sky site, however, a 3- or 4-inch telescope will show it easily.

Lovejoy makes its closest approach to Earth (some 44 million miles away) in early January, and the result is that it races across our sky. The comet covers 3° per day at its peak. This means it will move noticeably in a single observing session.

Amateur astronomer Terry Lovejoy discovered this object August 17, 2014, from Brisbane, Australia. Comets that first light up the deep southern sky tend to have orbits inclined steeply to the solar system's plane, a characteristic that often carries them well north after they wheel around the Sun. That's the case with C/2014 Q2 — Lovejoy's fifth discovery — as it was with his fourth, C/2013 R1. Both the latter comet and Lovejoy's most famous find, sungrazer C/2011 W3, reached naked-eye visibility. Although this latest Comet Lovejoy won't be as bright, it still will be fun to follow.



This 8th-magnitude visitor to the inner solar system sprints northward during January, moving from Lepus to the doorstep of Andromeda.



The ringed planet shines brightly before dawn throughout January, but it saves its best show for when the crescent Moon passes by January 16.

noticeably in recent years and is now smaller than at any time since scientists started measuring it — though it's still wider than Earth.

If details appear fuzzy, wait until Jupiter climbs higher in late evening. The greater altitude means its light travels through less of Earth's turbulent atmosphere. The planet appears highest in the south after midnight.

Once you've soaked up photons from Jupiter itself, turn your attention to the planet's four large moons. These worlds show up easily through small telescopes, and watching them change positions as they orbit the planet provides many thrills. For the first time in five years, the satellites' orbital plane now tilts nearly edge-on to the Sun and Earth. This ushers in a series of "mutual events," where one moon may pass in front of another (an occultation) or enter another's shadow (an eclipse). Dozens of such events occur this month. In addition, each satellite traverses Jupiter's disk and casts its shadow onto the jovian cloud tops once every orbit.

But satellite events reach a crescendo the night of January 23/24 when three moons and their shadows cross the planet's disk and Callisto eclipses Io. The action begins at 10:11 P.M. EST when Callisto's shadow first touches Jupiter. Io's shadow follows at 11:35 P.M. and Europa's at 1:27 A.M. For the next 25 minutes, all three shadows appear as black dots on the planet's cloud tops. Don't miss this rare triple shadow transit — there won't be another until 2032! Io's shadow leaves the disk at 1:52 A.M., Callisto's at 3:00 A.M., and Europa's at 4:22 A.M.

The moons themselves appear silhouetted against Jupiter's disk from 11:54 P.M. to 2:12 A.M. (Io), 1:19 to 6:02 A.M. (Callisto), and 2:08 to 5:02 A.M. (Europa). That leaves a brief four-minute interval (2:08 to 2:12 A.M.) when the three moons are simultaneously in transit, though Io and Europa are on the planet's limb.

The night's other impressive event comes when Io passes into Callisto's shadow. The eclipse begins at 12:41 A.M. and concludes 18 minutes later. Observers should notice Io dimming, particularly near the event's middle. The mutual eclipse offers a tasty morsel in a smorgasbord of events Jupiter viewers won't soon forget.

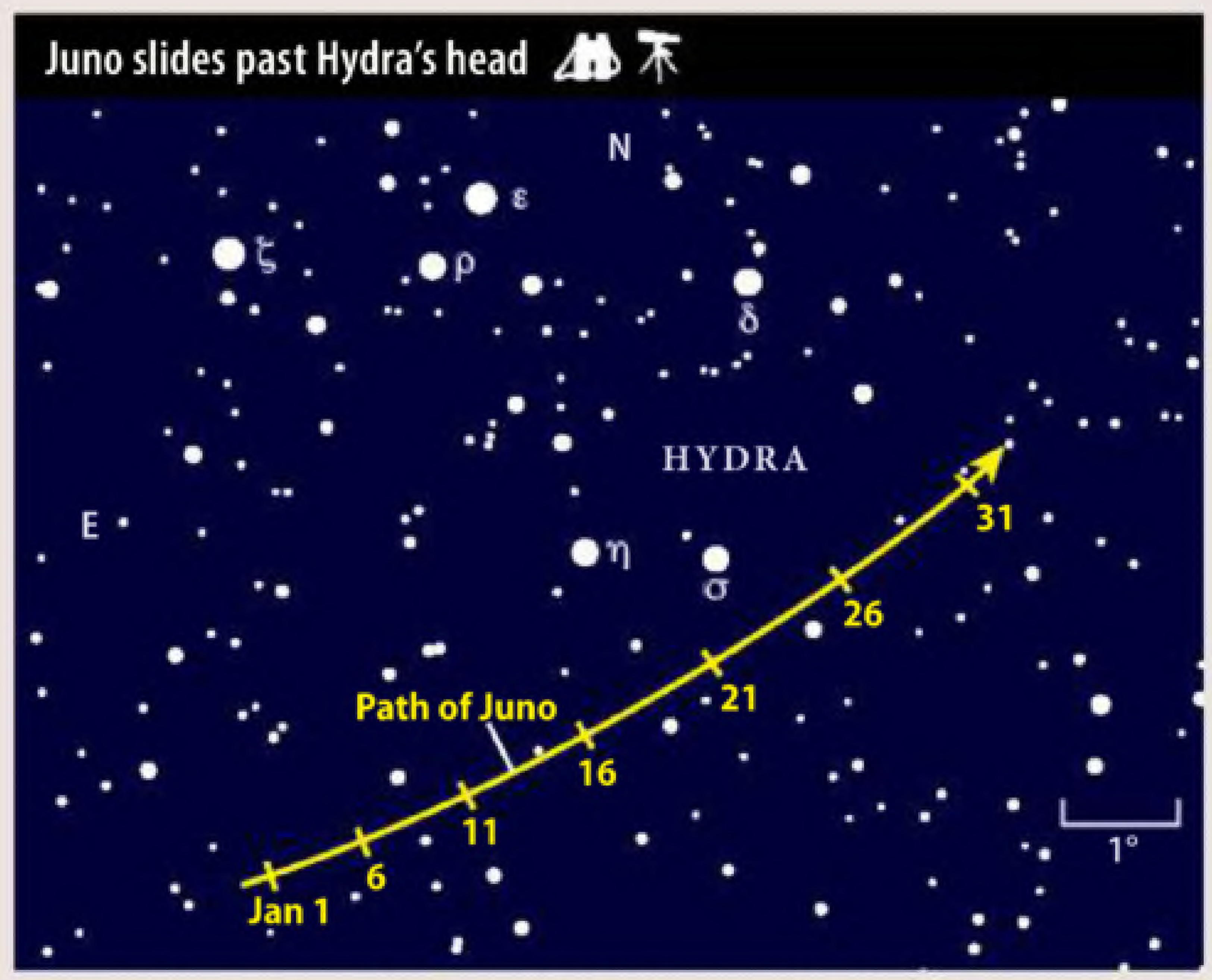
LOCATING**ASTEROIDS**

Bashful Juno steps into the spotlight

Newcomers to the art of asteroid tracking will be happy to add 3 Juno to their catches. Although it was the third asteroid discovered, it doesn't often glow brightly enough to be our monthly pick of the litter.

Juno reaches opposition and peak visibility January 29, but it remains an 8th-magnitude object all month. The asteroid rises in early evening following the bright stars of winter. Sirius appears on the right, Jupiter on the left, and the head of Hydra is in between. Juno resides within a few degrees of the head throughout January. The asteroid could pass incognito among the stars in this region, so use the chart below to zero in on its position. You should be able to identify it directly. If not, make a sketch of the four brightest stars in the field and come back a night or two later. The object that moved is Juno.

Astronomers number asteroids by the order of their discovery. Naturally, the brightest ones showed up first. So why isn't Juno bright every year like 1 Ceres and 4 Vesta? Juno has a fairly eccentric (oval-shaped) orbit, so it spends more of its time far from the Sun. It's also the smallest of the first four asteroids found, spanning just 170 miles. German astronomer Karl Harding discovered Juno on September 1, 1804, when it happened to be near its closest.



Asteroid Juno glows at 8th magnitude this month as it reaches opposition and peak visibility. Its path takes it through the northern part of Hydra.

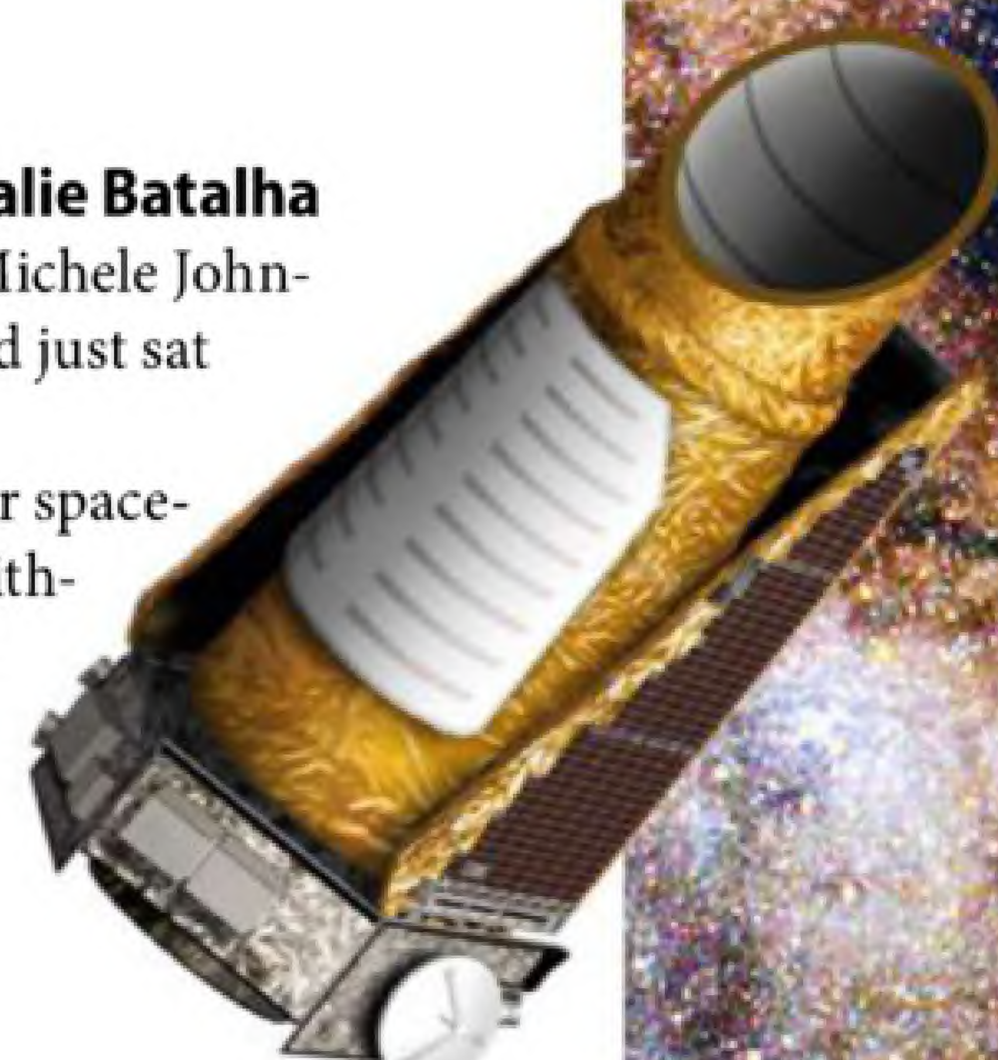
Although **Saturn** passed behind the Sun from our perspective in November, it quickly returns to prominence before dawn. The ringed planet rises by 4:30 A.M. local time January 1 and about two hours earlier by the 31st. A slender crescent Moon makes a lovely pair with Saturn when it passes 2° north of the planet January 16. One day later, Saturn crosses the border from Libra into Scorpius.

The ringed world shines at magnitude 0.6 and appears slightly yellowish. It contrasts nicely with the ruddy magnitude 1.1 glow of Antares, the Scorpion's brightest star, which lies 10° below it. When viewed through a telescope, Saturn's disk spans 16" and its rings extend to 36".

Having enjoyed four successful years of planet hunting, Kepler is now poised to revolutionize new areas of astrophysics. That is, assuming nothing else goes wrong.

by C. Renée James

KEPLER SPACE new



► K2's second campaign focused in Scorpius during fall 2014.

BILL AND SALLY FLETCHER (SCORPIUS); NASA (KEPLER)

On May 14, 2013, Kepler Mission Scientist Natalie Batalha was celebrating her birthday with her good friend Michele Johnson, a NASA communications director. The pair had just sat down to lunch when Johnson's phone beeped.

"It wasn't good news," Batalha recalls. The Kepler spacecraft had lost the second of four reaction wheels. Without the ability to maintain precise pointing, Kepler would no longer be able to carry on with its primary science mission to search for exoplanets. Batalha felt as though she had lost a close friend.

With a spacecraft 40 million miles (60 million kilometers) from home and incapable of keeping itself from rolling over, a less determined group might have given up. Instead, the Kepler team found a way to let the Sun point the way for them.

NASA positioned its hobbled telescope perfectly, like a pencil delicately balanced on the tip of a finger, so that oncoming photons of sunlight will exert constant force in just the right place. Solar pressure now acts in place of Kepler's lost second wheel, stabilizing the spacecraft and allowing it to point at a specific section of sky for months at a time. The spacecraft must be rotated following each campaign of up to 83 days to prevent sunlight from entering the telescope.

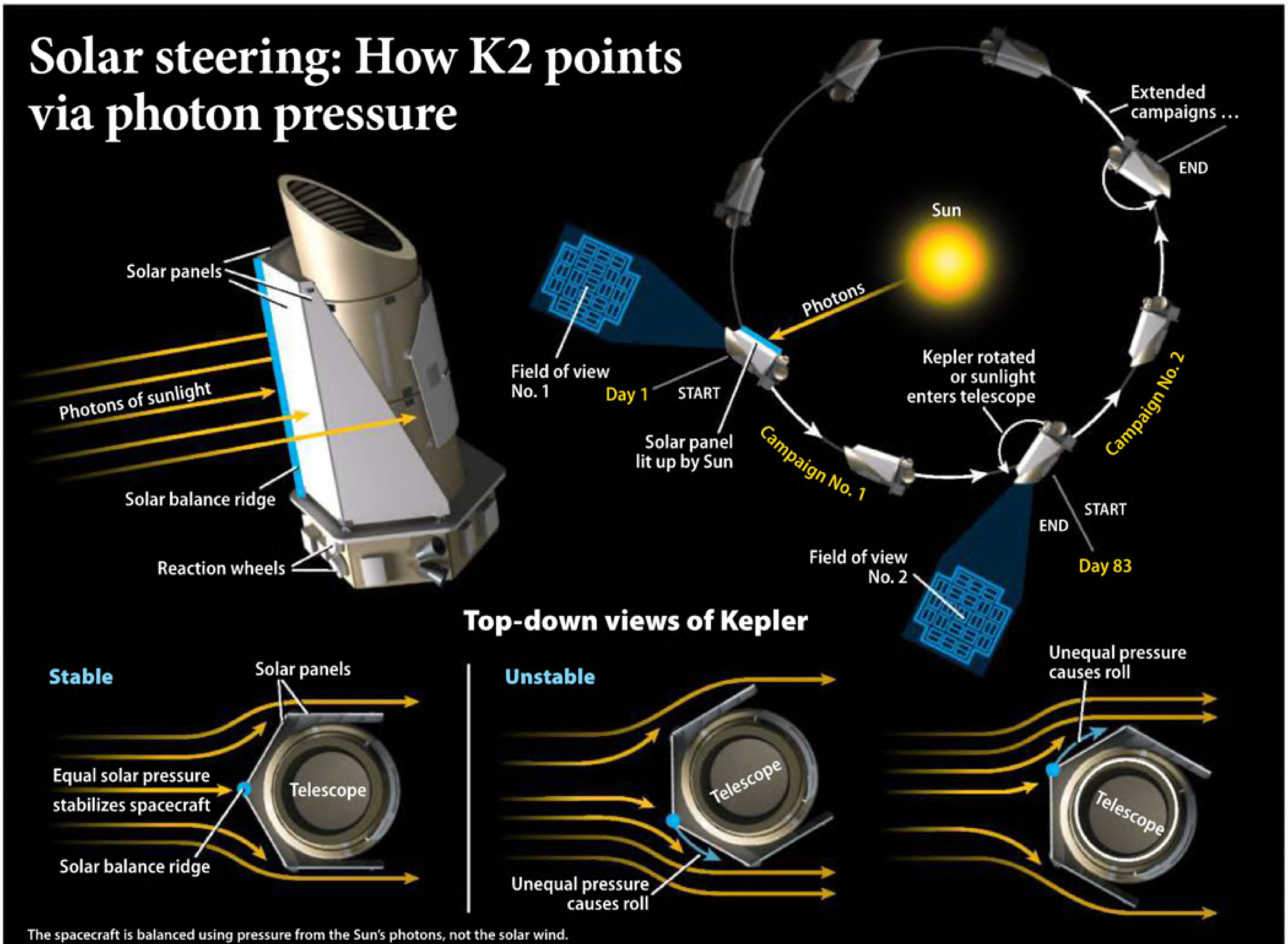
After more than a yearlong hiatus, Kepler has resumed its studies of the sky. NASA calls the spacecraft's second chance "K2."

Telltale dips

Bill Borucki joined NASA more than half a century ago working to develop the heat shield for the Apollo Program. His far-fetched vision helped turn discovering Earth-sized planets around other stars into a reality. If everything in a distant solar system happened

C. Renée James *is a professor of physics at Sam Houston State University in Huntsville, Texas, and author of* Science Unshackled *(Johns Hopkins University Press, 2014).*

CRAFT'S lease on life



Photons from the Sun put constant pressure on the spacecraft. Despite two broken reaction wheels, engineers devised a way to steer Kepler by delicately balancing this slight force. Now that Kepler has been balanced, the telescope is stable enough to continue collecting images nearly as crisp as before. A particular section of sky will be monitored constantly during an 83-day campaign before NASA must turn the spacecraft and start again to avoid pointing the telescope at the Sun. Astronomers say this series of campaigns will open up new types of science for the already successful spacecraft.

ASTRONOMY: ROEN KELLY, AFTER NASA AMES/W. STENZEL

to be aligned just right, he argued, the passage of an Earth-sized planet across the face of its star would cause the light intensity to diminish. Nobody disputed that point. It's just that detecting this drop in light was impossible.

It took decades for technology to catch up to — and for the astronomical community to warm up to — Borucki's dream. The result was a space telescope that could watch a vast patch of sky, simultaneously measuring minute changes in the light of thousands of stars so astronomers could complete a planetary census. That dream culminated when Borucki was named the Kepler mission's principal investigator.

His team watched anxiously as the exquisitely sensitive spacecraft launched March 6, 2009. After a few test runs, Kepler began gathering science-worthy data May 12 of that same year. Engineers at Ball Aerospace had essentially guaranteed four good years of science with the $600 million mission. Those four years ended just two days before the second reaction wheel failed. Kepler engineers and astronomers alike regard the timing with a measure of ironic humor.

The reaction wheels provide stability to Kepler in the same basic way that your spinning bicycle wheels keep you from toppling over as you ride. To fully understand their importance to the mission, try balancing on a bike when it's not moving.

"Another four years would have been frosting on the cake," Borucki said at a swiftly called NASA press conference the day after the fatal reaction wheel failure. "But we have a nice cake now."

It's a cake whose ingredients include some 1,000 confirmed planets, over 4,000 strong planetary candidates, and more than 2,000 eclipsing binary stars. Pondering the presence of Earth-like planets around other stars was the realm of science fiction only a few decades ago. Even after the discovery of planets around main-sequence stars, few resembled what most people would recognize as a terrestrial world. Most were so-called "hot Jupiters" — gas giants orbiting alarmingly close to their host stars. No true Earth twin has been discovered, but Kepler has come the closest.

Kepler observations also have proved to be a rich mine of data on variable and pulsating stars and a host of other stellar nuggets, all within the spacecraft's original field of view in the constellations Lyra and Cygnus. This benign field includes 150,000 fairly average stars deemed most likely to host detectable planets. NASA chose the area in part for its location outside the ecliptic plane — the plane

created by Earth's orbit around the solar system — so that Kepler never would have to wrestle with the glare from the Sun.

It was the cosmic equivalent of staring endlessly at the suburbs, but it was the surest way to perform the planetary census that was Kepler's reason for being. Unfortunately, when the reaction wheel failed, those suburbs were out of reach.

Action and reaction

Finding Earth-sized planets is a job that requires equal doses of patience and precision, in both light detection and pointing. To maintain stability along the three rotation axes, Kepler needed three working reaction wheels. These heavy, solid wheels are each about the size and shape of a top hat. They're mounted to the outside of the spacecraft and rotate rapidly on a low-friction bearing. As they spin one direction, the telescope responds by spinning slowly in the other.

One of the advantages of reaction wheels is that they are powered by Kepler's solar panels, giving astronomers the ability to position the craft without using its precious and finite fuel. The reaction wheels provide stability to Kepler in the same basic way that your spinning bicycle wheels keep you from toppling over as you ride. To fully understand their importance to the mission, try balancing on a bike when it's not moving.

The loss of the first wheel — reaction wheel No. 2 — only three years into the mission was disappointing, but not fatal. Ball Aerospace still had three dimensions of control, but now there were no spare parts. Unlike the Earth-hugging Hubble Space Telescope, Kepler is too far away in its 372.5-day solar orbit for astronauts to service. All the Kepler team could do was cross their fingers and hope another reaction wheel would not fail.

Roger Hunter, the Kepler mission manager at the time, had acknowledged just months before its failure, "Reaction wheel No. 4 has been something of a free spirit." Twice a week, Kepler communicated its health status to flight operations at Ball Aerospace. Reaction wheel No. 4 had frequently shown erratic friction signatures that cleared up as mysteriously as they developed.

On May 14, 2013, Kepler entered yet another safe mode — a protective state where it pointed its solar panels to the Sun and awaited instructions from Earth — and everyone immediately suspected reaction wheel No. 4 with good reason. The wheel had ground to a halt, its motor trying desperately to turn it. This was no friction anomaly. It was a catastrophe.

Astronomers aired their laments at Kepler's demise. Even as NASA officials said the mission might not be over, many figured it would never again do what it had been designed to do. It appeared that the mission's primary science goal, finding the frequency of Earth-sized planets, had come to an end.

Two of Kepler's four reaction wheels are visible right of center in this image of the spacecraft being assembled by Ball Aerospace employees. BALL AEROSPACE

Bill Borucki, Kepler's principal investigator, speaks at a press conference at NASA Headquarters in 2010. NASA/PAUL E. ALERS

Famed planet finder Geoff Marcy of the University of California, Berkeley, even penned a poem inspired by W. H. Auden's "Funeral Blues." It read in part:

Stop all the clocks, cut off the Internet,
Prevent the dog from barking with a juicy bone,
Silence the pianos and with muffled drum
Bring out the coffin, let the mourners come.
Let jet airplanes circle at night overhead
Sky-writing over Cygnus: Kepler is dead.

But NASA had designed Kepler with this day in mind. The spacecraft's thrusters had kicked in to control stability. Kepler went into a steady roll that allowed it to maintain communications with Earth.

If your home Dobsonian telescope did this, it wouldn't be an insurmountable problem. You would just move your head to follow the eyepiece. However, explains John Troeltzsch, Kepler mission program manager at Ball Aerospace, "With Kepler, it creates arcs instead of points on the detectors." Points are crucial for the telescope to measure minuscule brightness variations.

Two-wheeling it

NASA sent commands for weeks in an attempt to jostle the two dead wheels loose. Although the wheels did eventually move, the friction in them was so great that the whole craft vibrated in response, killing any chance of getting useful scientific data. NASA finally declared defeat in August 2013. Data collection for the mission was officially over. But that didn't mean they had to give up completely.

Engineers realized that, if oriented properly, the spacecraft could use the force of sunshine as its third reaction wheel. Distinctly different from the wildly variable solar wind of fast-moving charged particles, radiation pressure from sunlight on the spacecraft is minuscule — about the same as the weight of a fly on your desk. Although tiny, this steady force would, in principle, keep Kepler precariously balanced on a solar tightrope.

Using the Sun meant that the spacecraft would have to lie down, shifting its gaze to objects in the ecliptic plane. The most

An array of 42 CCDs makes up Kepler's focal plane. Together, the CCDs produce a 95-megapixel image. NASA/BALL AEROSPACE

energy-efficient configuration would have Kepler constantly oriented perpendicular to the Sun, with creative thruster maneuvers helping astronomers squeeze out a series of 83-day observing campaigns. No, it wasn't four solid years like the original Kepler mission, but it was good enough for detecting short-period exoplanet transits and more than good enough for dozens of other astrophysical events.

"The Ball Aerospace engineers were amazing," Batalha recalls. Engineers found the sweet spot for pointing the telescope and then worked with astronomers to determine whether they could do quality science in the new configuration.

"We'd come [to meetings] every week and every month," explains Martin Still, director of the Kepler Guest Observer Program. "And we'd revise our [science] expectations higher and higher. What we now have is a mission capable of achieving almost the same photometric precision, but pointing in all of these different locations along the ecliptic plane."

Now, instead of staring at a field that was, cosmically speaking, fairly average, the telescope could explore young stars, active suns, galaxies, star-forming regions, and more. The ability to get such high-quality data piqued the interest of the astronomical community. Within months, researchers submitted 42 proposals for science on the two-wheeled spacecraft.

"The answer to everything?" the Kepler team joked in a nod to the Douglas Adams classic. Possibly, but not without funding. With Kepler's demise, the operations budget was scheduled to be zeroed out October 1, 2014. Impressive on paper, K2 needed to prove itself worthy of continued funding by NASA. The team submitted a proposal to NASA's Senior Review of Operating Missions in the spring of 2014. The spacecraft's fate was in their hands.

Even with Kepler's reputation, renewed funding was anything but a given. K2 was on the table with eight other missions that had lived past their prime.

"The operation of the nation's space borne observatories is so severely impacted by the current funding climate in Washington that the Senior Review Panel feels that American pre-eminence in the study of the Universe from space is threatened to the point of irreparable damage if additional funds cannot be found to fill the projected funding gaps," the final review report read.

By the time Kepler had stopped actively observing, the mission had a reduced \$18 million annual budget. Ultimately, NASA approved the extended mission at a cost of \$10 million a year, some 10 percent less than Kepler managers had requested.

Meanwhile, data analysis from the first phase is still ongoing at a cost of about \$8 million a year. "In essence, we are finishing Kepler and flying K2 for the same total cost we were planning to use just to continue flying Kepler," says Charlie Sobeck, NASA project manager for the mission.

In securing funding, K2 had cleared a major Earth-bound hurdle. And in September, NASA announced a reassessment of the spacecraft's fuel had netted a 25 percent increase, providing enough to burn through 2017 and possibly beyond.

K2 intends to live life to the fullest until then.

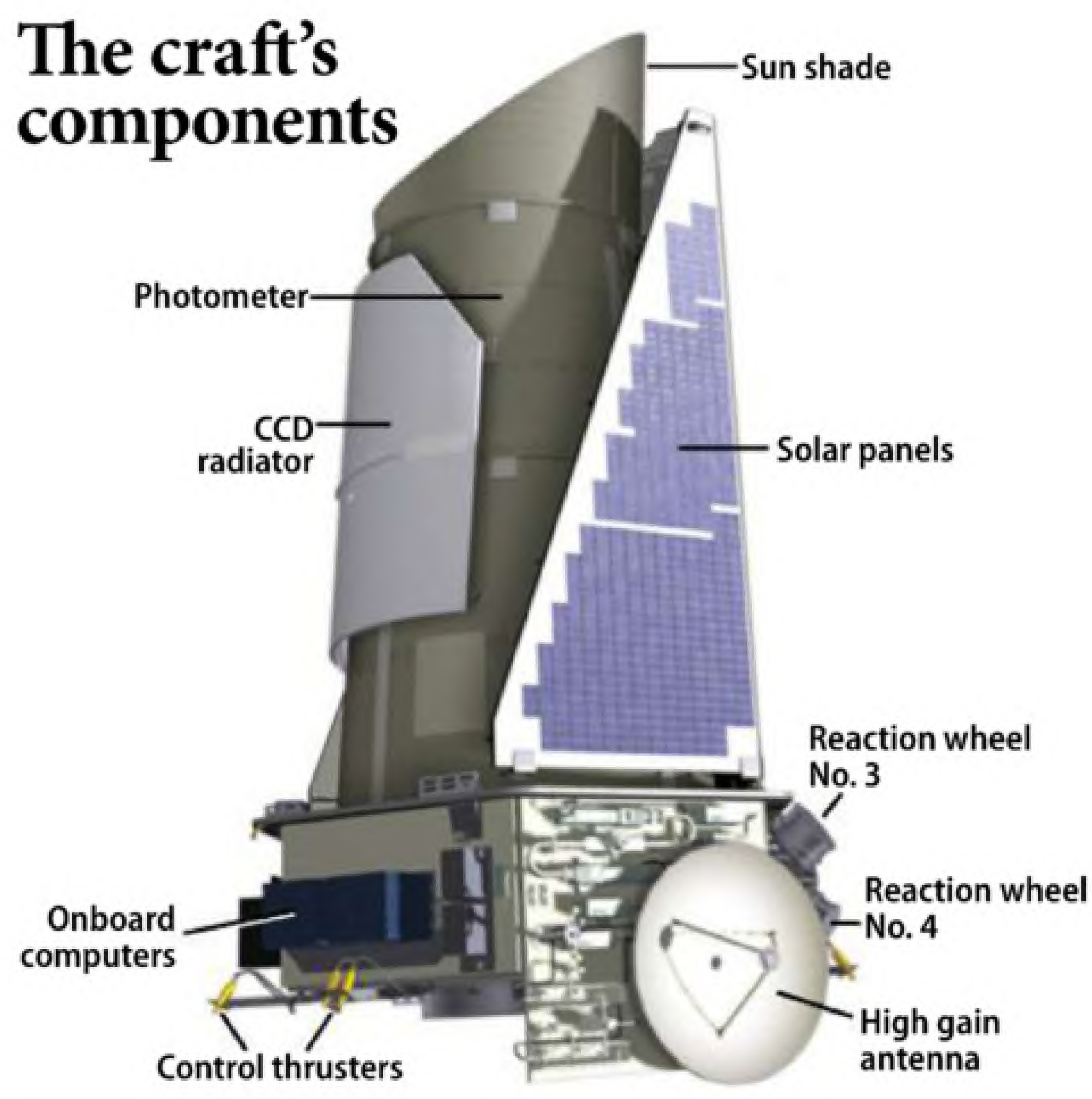
Something for everyone

Assuming nothing else goes awry, K2 is on target to fill in major gaps in several areas of astrophysics. Engineers performed a preliminary engineering run — Campaign 0 — in the spring of 2014. The first two science campaigns were completed by the end of the year. K2 team members happily reported that, although its target field has changed considerably, the spacecraft's ability to detect minute changes in light intensity has not diminished much.

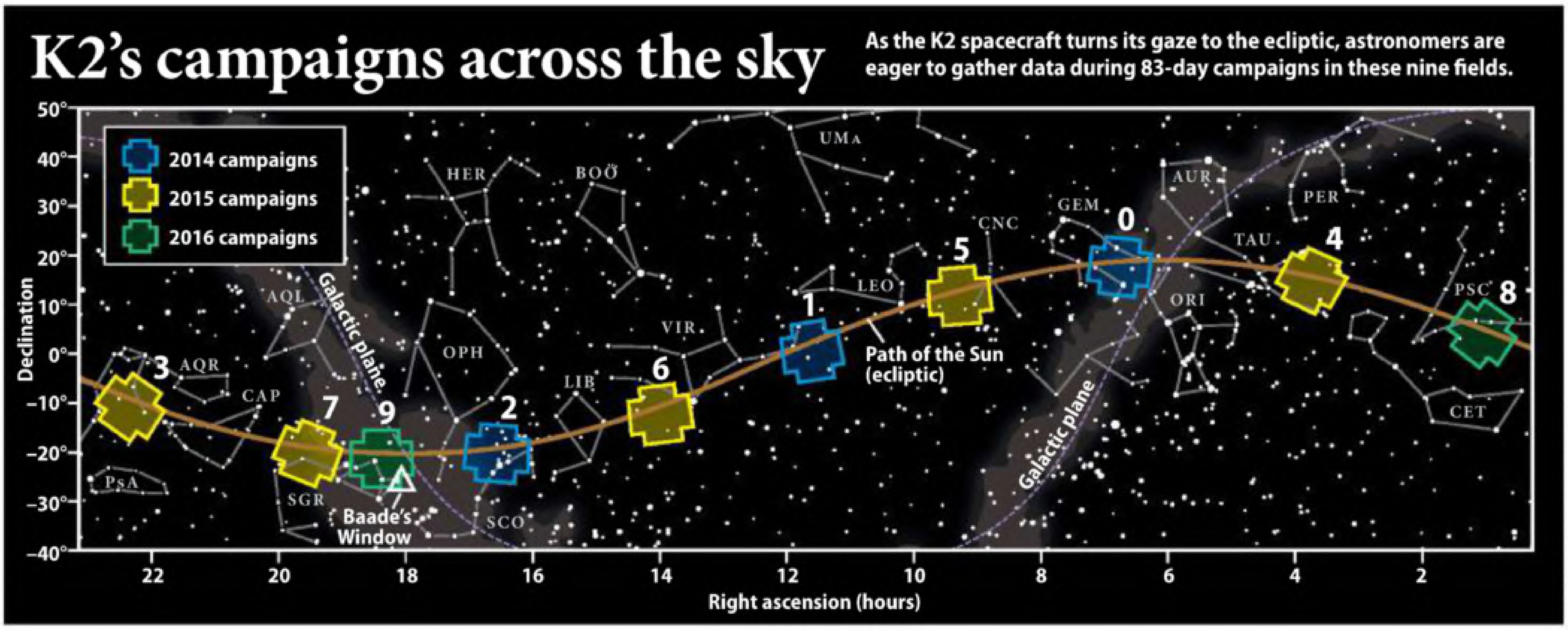
"Imagine the tallest skyscraper in New York City," explains Batalha. "It's nighttime, and every room is occupied and all the lights are on. One person goes to the window and lowers the blinds by a few centimeters. The spacecraft would be able to measure the resulting change in brightness."

The various regions in the campaign have been mapped out, but individual targets are still up for grabs, assuming the case can be made to look at them. Every new field of view easily will contain 10,000 denizens of the cosmic zoo. The astronomical community is rarely presented with the chance to obtain data from such a precise instrument. Now, every six months or so, astronomers will have the chance to throw their projects into the ring for consideration.

The craft's components



Two of Kepler's four reaction wheels are visible in this diagram of the spacecraft. Reaction wheel No. 4 failed May 14, 2013. The wheels are critical for controlling the telescope's pointing accuracy. BALL AEROSPACE



Exoplanet astronomers can get a census of worlds in star clusters whose ages range from a mere 2 million years to the age of the Milky Way itself, helping fill in the gaps in our understanding of the evolution of stellar systems.

For astronomers interested in precisely measuring the masses, diameters, and other properties of binary systems, K2 promises about a dozen new eclipsing binary stars per campaign.

The spacecraft also will shed light on supernovae. By staring at 105 square degrees of sky — a region twice the size of the Big Dipper's bowl — nonstop for over two months at a time, K2 will almost certainly catch several stars in the act of exploding in distant galaxies. "For every 1,000 galaxies we observe, we expect to detect one supernova," Still says. "This is completely unique. K2 is going to be observing the galaxy before the supernova goes off, observing the supernova event directly as it happens, and observing the [light] decay of that supernova." Nothing else astronomers currently have at their disposal can provide this vital information.

Of particular interest are type Ia supernovae, cosmic explosions that all have the same maximum brightness, making them useful tools for gauging universal distances. "There is a grand debate about what causes a type Ia supernova, which is a standard candle that tells us how large the universe is," Still says. "Nobody really knows what a [type] Ia is, but these observations have the potential to rule things out."

If the mission makes it as far as Campaign 9, the field of view will pass close to the galactic center, catching the attention of high-energy astronomers who look at exotic objects like black holes and X-ray binaries.

"We're going to be staring directly into Baade's Window," Still says of the potential Campaign 9. This dust-free region of the sky offers a comparatively unobscured view into the Milky Way's bulge. "We're hoping — fingers crossed — that we can spend a large number of our resources for that campaign looking for the microlensing of planets around those stars toward the galactic center."

In planetary microlensing events, a planet's gravitational field becomes a magnifying glass for background light sources.

> **"Imagine the tallest skyscraper in New York City. It's nighttime . . . and all the lights are on. One person goes to the window and lowers the blinds by a few centimeters. The spacecraft would be able to measure the resulting change in brightness." — Natalie Batalha**

This artist's illustration shows the first Earth-sized planet found orbiting in the habitable zone of another star. It sits about 500 light-years from Earth in the constellation Cygnus. NASA AMES/SETI INSTITUTE/JPL–CALTECH

K2's precision could give astronomers a better count of cold, lower-mass planets as well as provide a census of free-floating planets.

Of course, none of this is to say that astronomers were ecstatic about Kepler's reaction wheel failures. Continuing observations of its original field would have helped find planets more like the ones in our solar system, ones whose sizes are more Earth-like and whose orbital periods aren't so short. "This event has disappointed many, many people," Still says.

But astronomers have a habit of making the most of whatever the universe throws at them. Bad weather? Wrong time of year? Wrong hemisphere? Astronomers have always wrestled with elements beyond their control.

And in the grand tradition of NASA missions kept afloat by the sheer determination of team members, the Kepler crew stunned even many in the astronomy community when their ingenuity resurrected the space telescope.

Kepler has already revolutionized humanity's perspective of the cosmos with its thousands of planet candidates. Now, as the spacecraft turns its eye to the ecliptic, similar possibilities for surprises have emerged in all new areas of science. That is, assuming nothing else goes wrong.

FIND OUT ABOUT FUTURE MISSIONS TO HUNT FOR EARTH-LIKE WORLDS AT **www.Astronomy.com/toc.**

The planetarium world meets in China

As dark skies diminish, the International Planetarium Society meets in Beijing to discuss its members' greater responsibility in bringing the stars down to Earth. **text and images by David J. Eicher**

Every year, some 92 million people see a planetarium show somewhere around the world. This incredible figure means that planetariums, which are rapidly transforming from simple structures into full-blown, full-dome theaters, play a huge role in bringing a first view of astronomy to the public. This is especially true in an era when light pollution casts a blight on the lives of so many people; the majority of us on Earth never really get to see a truly dark sky. So the role of planetariums is critical in bringing astronomy to the public.

Every two years, the International Planetarium Society (IPS), the group of professional planetarium producers, astronomers, creators, writers, and artists, gathers for a large meeting to discuss the planetarium world. This time the meeting took place in Beijing, June 23–27, 2014, and was hosted by the Beijing Planetarium, a spectacular facility that is the keystone planetarium in China. I was fortunate enough to be invited to deliver one of the four keynote addresses at this meeting, and so experienced my first foray with the planetarium world.

Instrumental to my invitation and subsequent trip were Jin Zhu, director of the Beijing Planetarium, the marvelous astronomer Ziping Zhang of the planetarium, and Thomas Kraupe, president of the IPS. It was an amazing gathering and brought together more than 350 people.

Jin Zhu, director of Beijing Planetarium, welcomes guests to IPS 2014 — the first IPS conference to be held in China.

Starting strong

The IPS 2014 Conference got off to a spectacular start June 23. The venue for our gathering was lavish, with flourishes such as elaborate meeting spaces, fancy meals, and an opening ceremony that would have served well at the Olympics, including singing, choreographed young Chinese schoolchildren welcoming the group with a message of hope.

The local organizers, led by Zhu and accompanied by officers of the IPS, officially opened the meeting. Kraupe then delivered his initial remarks before giving way to a spectacular keynote address by

The massive and beautiful Beijing Planetarium, the first large planetarium in China, hosted the 22nd International Planetarium Society Conference, June 23–27, 2014.

***Astronomy* Editor David J. Eicher delivers his address, "Does the Universe Really Care About Itself?" at the Beijing Planetarium.**

IPS President Thomas Kraupe presides over a special session discussing the future of planetariums and science centers in educating and inspiring the public in astronomy and planetary science.

Ouyang Ziyuan, father of China's lunar exploration program, who spoke on the recent Chang'e 3 Moon mission and also numerous plans for future Chinese space exploration, including manned missions and a full-blown robotic exploration of the planets.

Smaller sessions also were highly impressive, focusing throughout the day on educating the public, new techniques in planetarium shows, and amazing previews of new programs from a slew of companies, highlighted by Sky-Skan and also featuring NSC Creative, Evans and Sutherland, GOTO, RSA COSMOS, Konica Minolta, Carl Zeiss, and others. It made for a great start to the conference, plus I really enjoyed seeing some old friends, including *Astronomy*'s great contributing writers Martin Ratcliffe and Martin George, as well as Glenn Smith, Jim Sweitzer, Mark Rigby, Carter Emmart, Shawn Laatsch, Derrick Pitts, Mark Webb, and others.

Planning for the future

June 24 began with my keynote address, "Does the Universe Really Care About Itself? Communicating Astronomy in the 21st Century." It focused on the challenges we have with spreading the truth about science in this age. I examined the trends making it hard for younger people to get into serious subjects like astronomy, influenced more and more as time goes on by fantasy versus reality, a constant stream of TV and other entertainment — much of which misses the important science announcements altogether and distorts the facts on the few they do cover — and a lack of awareness of the cosmos around them. I concluded by describing the numerous areas of great importance in astronomy, astrophysics, planetary science, and cosmology in which researchers have made huge strides in just the past few years.

Some of the staff of *Amateur Astronomer* magazine, China's largest astronomy publication, meet with *Astronomy* Editor David J. Eicher: (from left) editor and graphic artist Zhang Yi Jie; photographer Su Chen; artist Ma Xiaokun; Eicher; and director Li Jian.

"Does the universe care about itself?" I finished. "Yes, we born of the cosmos do care. But many more of us on this planet need to realize where we are and why we are here. It's a message that can liberate us all and make us a great, forward-moving civilization of the future.

"We need all the firepower we can get. The stakes are high. Knowing and appreciating the universe and how it works is too important to let slip away.

"As a friend of ours once wrote, this world has only one sweet moment set aside for us. That moment is now."

Following many conversations with attendees and smaller sessions highlighted by a talk about live presentations in planetariums, we had lunch, and then I set off for an appointment with Li Jian, director of *Amateur Astronomer*, China's biggest astronomy magazine, which is produced at the Beijing Planetarium. I was really touched by meeting the staff members, who treated me royally, and we shared much of the afternoon talking astronomy and magazines, including all aspects of what they are doing, as the magazine prospers with a circulation of 30,000. The hospitality from Jian and his colleagues Zhang Yi Jie, Su Chen, and Ma Xiaokun was really incredible. I think it is fair to say that we will be cooperating on some interesting things in the future, set to help the community of

astronomy enthusiasts in both China and the United States.

Tuesday night was once again set aside for demonstrations from producers of planetarium shows, and the many films in two different theaters wowed us with spectacular graphics and sequences. Among the companies presenting on this night were Sky-Skan (in conjunction with Sony, with a presentation narrated by Martin Ratcliffe, who, in addition to writing "The Sky this Month" in each issue of *Astronomy*, works for Sky-Skan), Fulldome.pro, Softmachine, Bella Gaia, Macro and Micro Digital Technology, Spitz, and Ohira Tech.

A look into the past

June 25 started up as usual, but it wouldn't be a typical conference day for long. Indeed, there were morning paper sessions presented by a variety of planetarium professionals, from a survey of customers at Adler Planetarium in Chicago to a history of planetarium projectors in China.

Attending members also heard a call for a new committee investigating the best quality options for providing audio in new-generation planetarium shows. But after lunch, the meeting took a break for two concurrent field trips.

David J. Eicher *is editor of* Astronomy. *He has enjoyed planetarium shows for many years.*

Sun Xiaochun of the Institute for the History of Natural Science, Chinese Academy of Sciences, delivers a lecture on astronomy in ancient China.

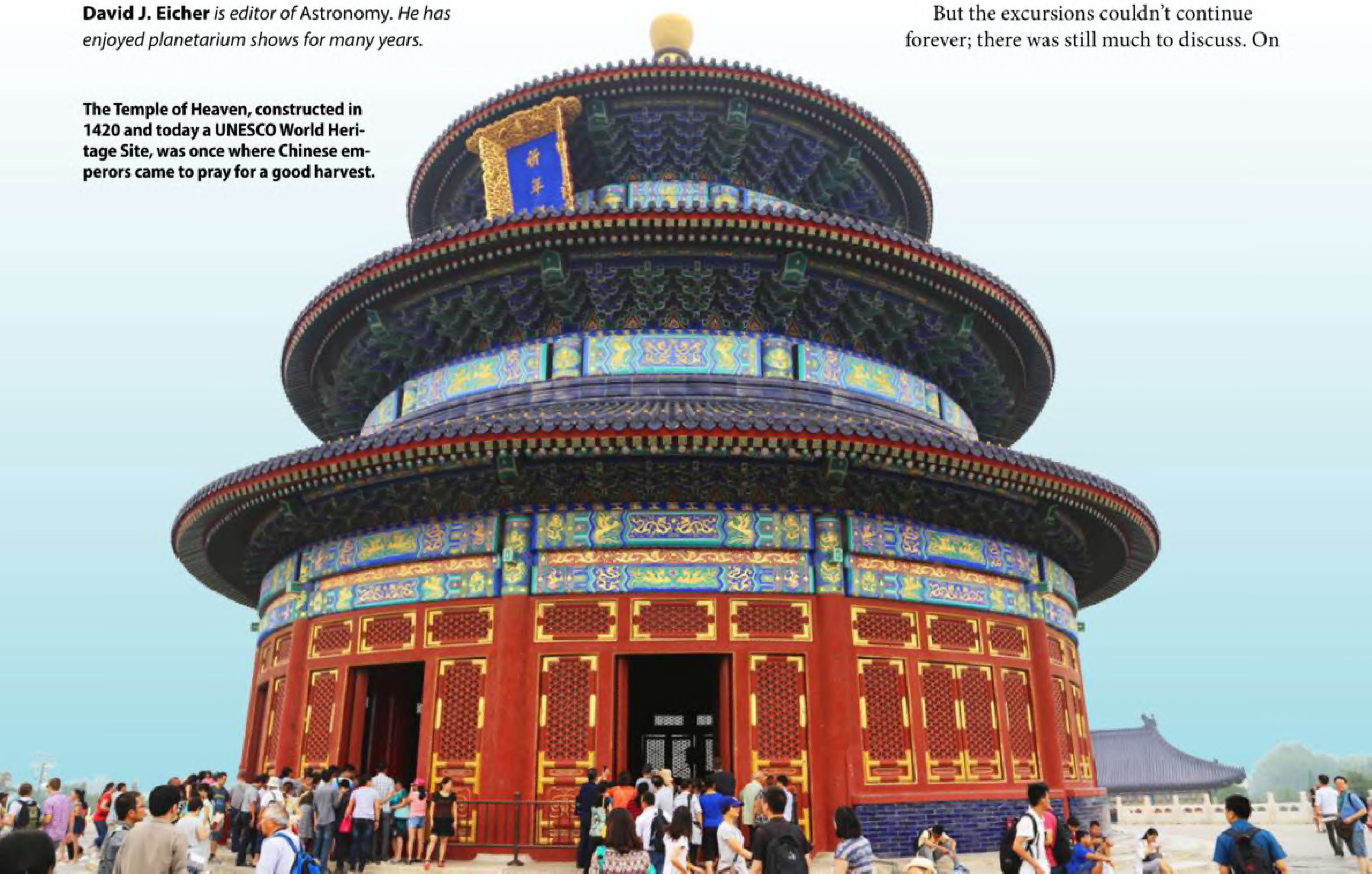
Derrick Pitts of the Fels Planetarium and Franklin Institute in Philadelphia enjoys a conference break.

Half the group traveled to the famous Forbidden City, which I saw when I was in China for the 2009 total solar eclipse. So I opted for the other trip, to a place I had not yet seen, Beijing's ancient astronomical observatory, one of the oldest on Earth.

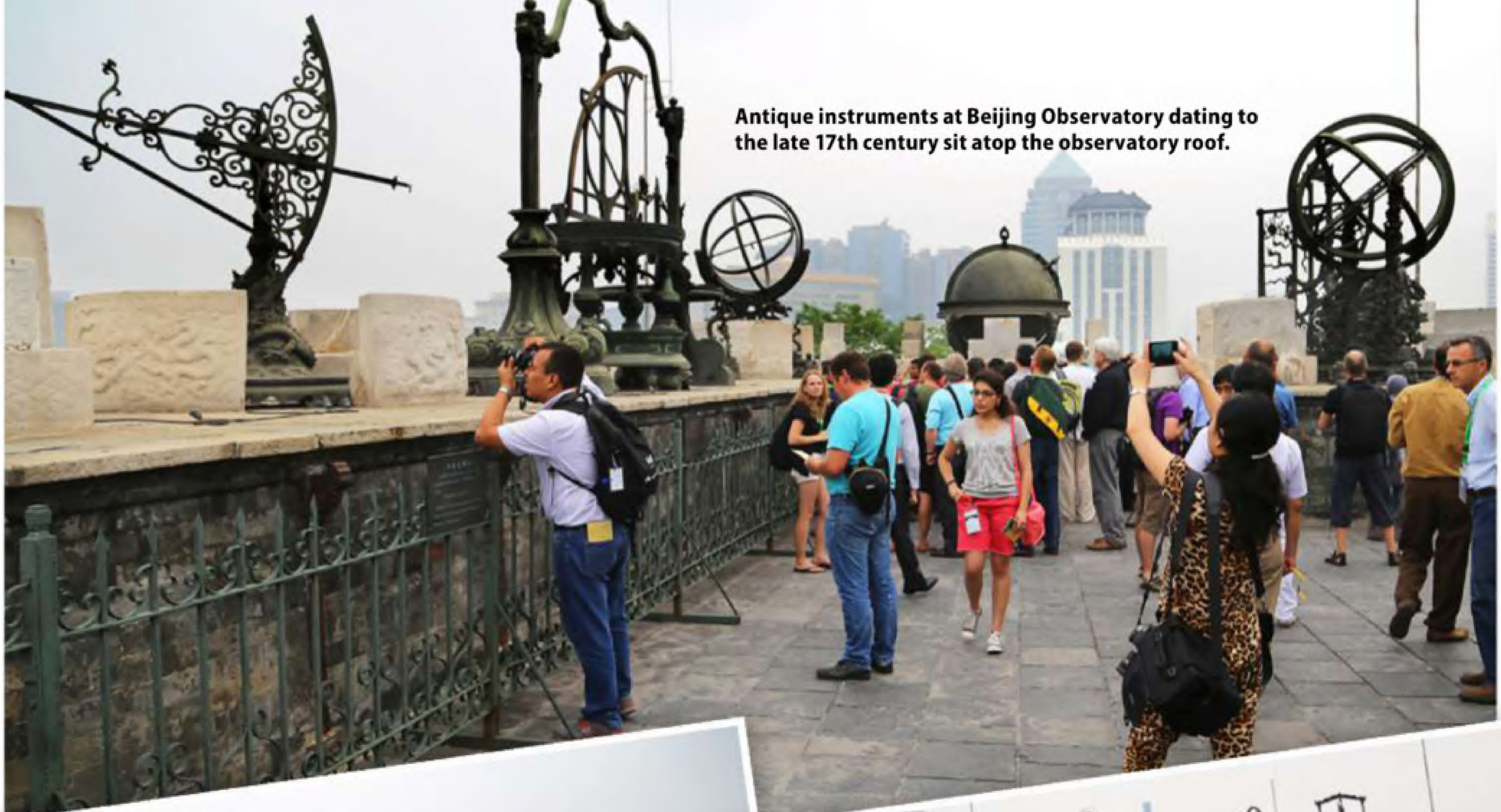
Beijing Observatory was founded in 1442, and its many instruments, crafted from iron and bronze and still in place atop the stone building, are absolutely incredible — from celestial spheres to armillary spheres to sextants to quadrants. Here was a high-tech science center of the 15th century, and the instruments now in place on the observatory's roof mostly date from the 17th century. It was absolutely stunning!

We also stopped at the Temple of Heaven, an incredible structure surrounded by vast grounds and many outbuildings where ancient emperors came to seek advice from the almighty and to offer sacrifices and make prayers for abundant harvests. What an amazing place to see.

But the excursions couldn't continue forever; there was still much to discuss. On



The Temple of Heaven, constructed in 1420 and today a UNESCO World Heritage Site, was once where Chinese emperors came to pray for a good harvest.



Antique instruments at Beijing Observatory dating to the late 17th century sit atop the observatory roof.

Instruments at Beijing Observatory include an ecliptic armillary sphere dating to 1673, a sextant dating to 1673, and an azimuth theodolite dating to 1715.

Beijing Observatory, founded in 1442, is one of the world's oldest astronomical observatories.

Reporter Xu Bin of China's *Science and Technology Daily* poses with Editor David J. Eicher after interviewing him about *Astronomy* magazine.

Nikolay N. Samus of the Institute of Astronomy of the Russian Academy of Sciences in Moscow provides a fascinating overview of the historical and present state of astronomy in the countries of the former Soviet Union.

IPS President Thomas Kraupe recognizes the IPS 2014 Conference Local Organizing Committee at the meeting's closing ceremony.

▲ Sky-Skan's Glenn Smith and Martin Ratcliffe — also an *Astronomy* magazine contributing editor — enjoy a break in the action at IPS 2014.

◄ Carter Emmart of New York's American Museum of Natural History, well known as a visionary in science visualization, enjoys the IPS 2014 Conference closing banquet.

June 26, Sun Xiaochun of the Institute for the History of Natural Science, Chinese Academy of Sciences, opened the day's activities with a fascinating overview talk about ancient Chinese astronomy, including the many advancements the culture made to the study of the skies and how their records still provide valuable data to astronomers today.

The IPS business meeting consumed much of the afternoon, concentrating on all manner of decisions and activities relating to the running of the society. We then had a group photo, and I had a most enjoyable dinner with good friends Martin and Shawn Ratcliffe.

Full-dome focus

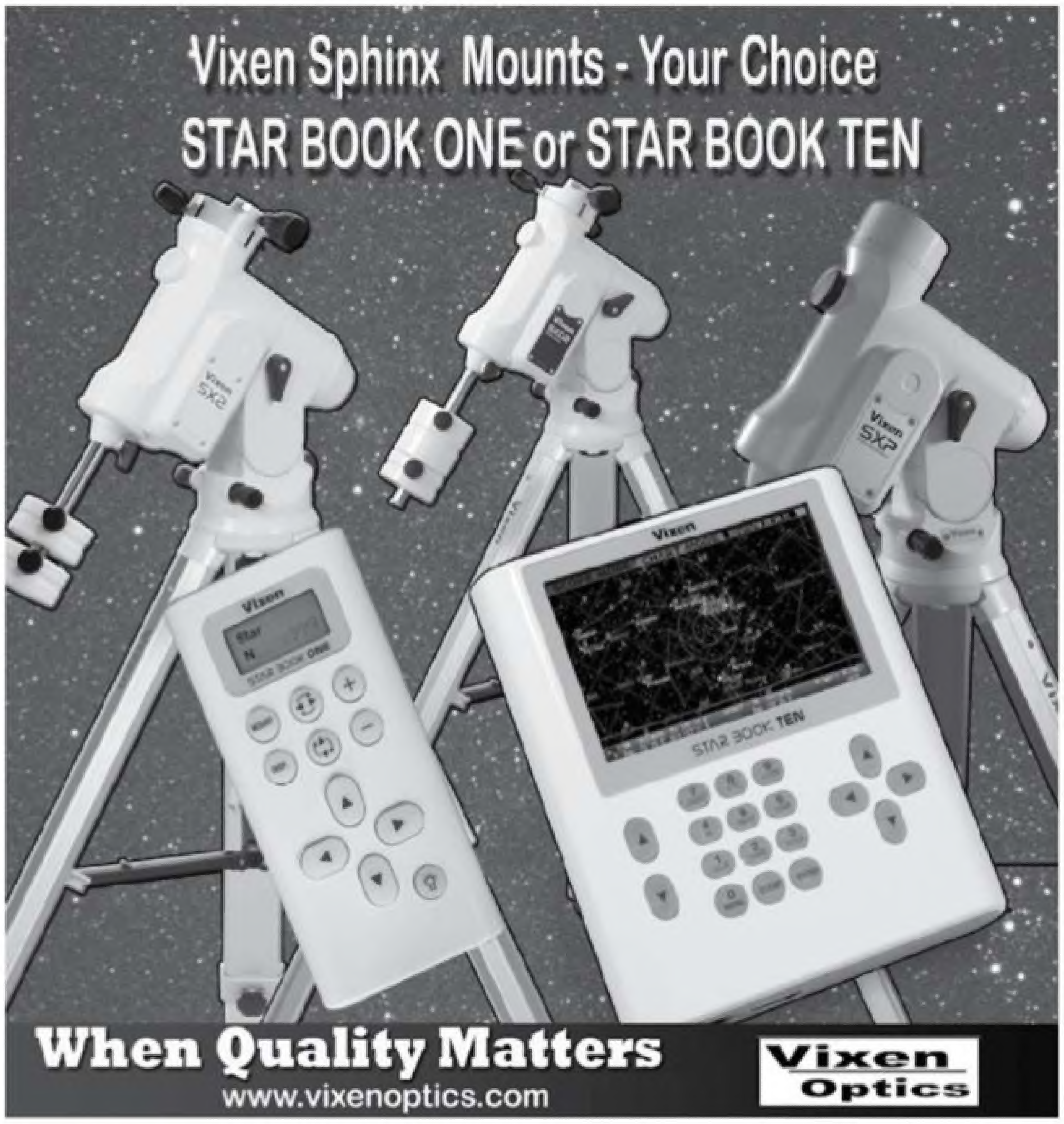
On the final day of the conference, Nikolay N. Samus of the Institute of Astronomy of the Russian Academy of Sciences in Moscow concluded the keynote addresses with a terrific summary of astronomy past and present in the countries of the former Soviet Union. The presentation contained lots of information that relatively few Westerners know about.

Following lunch, we were in for a treat. For the first time, the IPS hosted a planetarium content festival, and the finest productions from the event were featured in the Best of Fulldome Festival Presentation in the planetarium's 3-D theater. The award winners were absolutely incredible and covered a vast array of topics, from the mystery — and history — of flight to the wonders of circling Earth from above to the impact space exploration has had on our planet. I loved them all.

The IPS 2014 Conference ended with a lavish banquet at a restaurant across town, which included the closing ceremonies.

It was really an incredible time in Beijing. The discussions I had with many folks in the planetarium world left me confident about the future. After all, we must remember how important these facilities are in bringing millions of people their first encounters with the cosmos.

CHECK OUT MORE IMAGES FROM CHINA AND IPS 2014 AT **www.Astronomy.com/toc.**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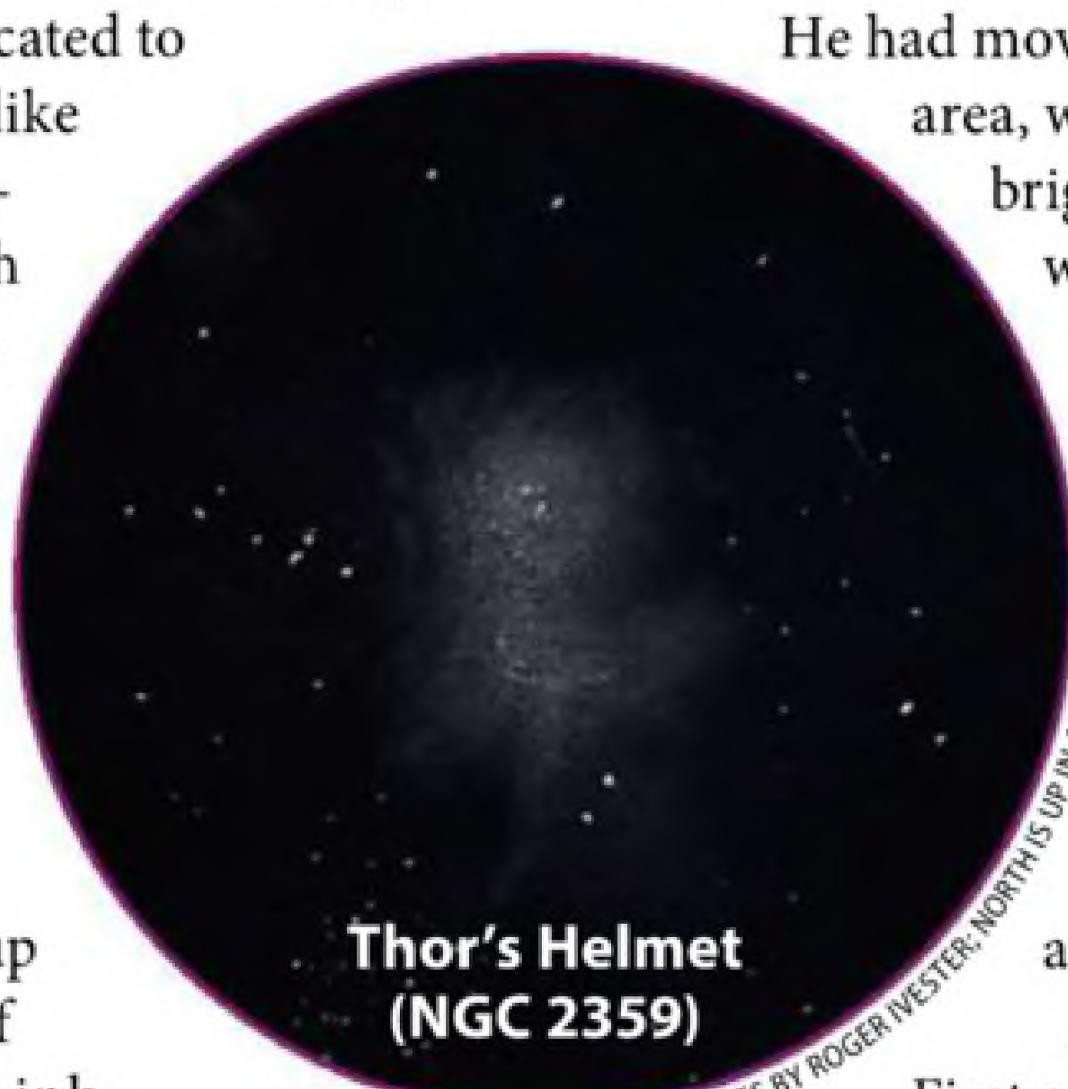
William Cho (landscape); Mike Reynolds (eclipse)

A visual observer's quest for greatness

With more than 1,000 sketches of deep-sky objects to his credit, Roger Ivester still just wants to observe. **by Maria Grusauskas**

For the past 10 years, Roger Ivester has juiced and consumed 5 pounds (2.3 kilograms) of carrots every day. That's 18,260 pounds (8,280kg) of carrots — and counting. Regardless of whether he shared the juice with his wife, or if a connection exists between carrots and improved vision (we'll get to that later), one thing is clear: The man is dedicated to visual observing, and like most amateur astronomers, his optical health is paramount to doing what he loves.

Ivester's fascination with astronomy began in the mid-1960s when his brother purchased a 2.4-inch refractor from Sears. Growing up in the rural foothills of North Carolina meant ink-black skies, and 12-year-old Ivester spent countless nights in a weedy field close to his childhood home, scanning the sky for the fabulous spiral galaxies and nebulae he'd seen in his science books.



Thor's Helmet (NGC 2359)

ALL SKETCHES BY ROGER IVESTER; NORTH IS UP IN ALL SKETCHES

Those early years were accompanied by the hum of a million insects singing in harmony, a glimpse of the occasional great horned owl in the distance, and the blue, orange, white, and rust-colored stars through his telescope's eyepiece — distant suns that made him wonder about life beyond Earth. But he didn't have much luck with galaxies. While he had formed an early companionship with the night sky, he had little in the way of guidance or star-hopping knowledge, and it would be years before he felt the unparalleled thrill of the most ancient observable photons soaking into his retina.

Ivester was 24 years old when he feasted his eyes on both Bode's Galaxy (M81) and the Cigar Galaxy (M82) for the first time, and he hasn't been the same.

He had moved to a light-polluted area, where finding even the brightest deep-sky objects with his new 4¼-inch Edmund Scientific reflector was proving difficult. But on that fateful night when he was just about to give up and go inside, he used his hands to block the ambient light.

And then it happened: First one small, faint object coalesced into view, and then the other. He savored the galactic pair for a long time and went to bed smiling. On that night, in his mind, Ivester became a real amateur astronomer.

The excitement of locating deep-sky objects never wore off, and he continued to hunt celestial targets through a 4-inch refractor and a 10-inch reflector. In 1990, Ivester began sketching his observations on notecards — his solution to not having anything to show for long nights spent traversing the cosmos. But documenting his observations in this way soon blossomed into a methodical exercise that would make him into a better, more attentive observer. Sketching, he says, added inches to his telescope.

Spiral galaxy NGC 891

Roger Ivester is a North Carolina amateur astronomer who has created more than 1,000 sketches of deep-sky objects. He's also a dedicated bicycler, with a lifetime total of more than 120,000 miles (193,100 kilometers). ROGER IVESTER

"Not only does [Ivester] eke out visual details others miss," says science and astronomy author Fred Rayworth, "he draws those objects as they are actually seen in the eyepiece, not some artistic rendering inspired by Hubble images."

Over the years, Ivester has compiled more than 1,000 of his what-you-really-see pencil sketches and 800 pages of meticulous notes on deep-sky objects, some of them so obscure that only a few other humans have ever laid eyes on them.

The old and new school

In today's increasingly digitized world, the No. 2 pencil as an observing

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Maria Grusauskas *is the community editor at Orion Telescopes & Binoculars and a freelance writer in Santa Cruz, California.*

The Milky Way passes above the palms April 28, 2014, at the southern sky lodge Farm Tivoli, where this imager stays in Namibia. GERALD RHEMANN

tool seems in danger of becoming extinct. Ivester sees himself among a dwindling number of amateur astronomers whose pencil sketches — not images — serve as lasting souvenirs of their observations.

Whether or not purely visual astronomy is on the decline is up for debate, although Ivester laments a marked drop in young people's interest. Retailers sell more than 300,000 telescopes in the United States alone each year, and while astrophotography claims a growing sector of the market, hundreds of online forums and astronomy groups around the globe indicate that visual observing is alive and well, although its practitioners may be growing older.

"Light pollution has probably also played a role in the loss of interest," says Ivester, who notes that at one time, most amateurs observed exclusively from their backyards. Today, the luxury of dark skies is often one that requires taking a trip.

The Crab Nebula (M1)

Without question, the recent advent of CCD cameras with their high efficiencies also has changed the hobby. Images allow us to see the colors and fainter magnitudes the human eye is incapable of detecting. But images also have drawn a curiously stubborn line between an old and new school that wasn't there before.

The late John Dobson once said that looking at a picture of a galaxy is cheating. "Nobody ever saw a galaxy with his cone cells; you see them with your rod cells," he told the BBC in 2006.

That's not to say that the visual purists of our day have rejected advances in technology. Digital planetarium software and sky atlas programs complement the well-worn star charts and logbooks of today's visual observers, but the visceral intent has remained the same: Those who put eye to eyepiece still sing the thrill of the hunt, finding one's way around the sky, and the deep personal connection with the observable universe that cannot be found in a photograph — people have to go there themselves!

"I've seen wonderful pictures of Yosemite or the Grand Canyon, but it's nothing like seeing it with your eyes," says visual observer Kevin Ritschel of California.

Globular cluster M22

As with many dedicated visual observers, Ivester's detailed documentation of the deep sky is less about prestige than it is about the personal satisfaction of returning to his notes later. He enjoys comparing his sketches to images the next day, digging up the names of faint smudges, and revisiting them in his telescope years later.

"I always seem to notice something different each and every time I make an observation," Ivester says. "It's always interesting to compare a sketch and notes from a previous observation. Sometimes I wonder how I missed certain features."

Seeing the Milky Way well — as in this image from Sand Beach in Acadia National Park in Maine — always means a great night of observing is ahead. NATE LEVESQUE

In 1993, for instance, while observing the spiral galaxy NGC 3893 in Ursa Major, he noted a faint smudge to the galaxy's southeast. Thumbing through his notes 10 months later, he remembered to look it up. The smudge was unlisted in the first two books he referenced, but to his elation, Roger Sinnott's *NGC 2000.0* identified it as NGC 3896, a 13th-magnitude spiral companion. "If I had not sketched NGC 3893 and logged the mysterious companion," says Ivester, "it is possible that I would have missed NGC 3896."

Twenty-one years later, Ivester returned to the faint pair. Although his glasses prescription has increased — indicating a decline in his overall vision — the two galaxies appeared exactly as he remembered them. "It is truly amazing how the brain can remember a faint galaxy pair after all this time," says Ivester. Equally amazing is the tenacious sensitivity of the rod cells in the human eye.

Using our eyes

Every time the lure of the pretty picture causes an amateur astronomer to bypass those long moments of contemplation at the eyepiece, the observer misses out on more than just the intoxicating experience of ancient light. The human eye really can see a lot.

Contrary to our daytime (photopic) vision, which our color-sensitive cone cells mediate, night (scotopic) vision is in the purview of rod cells. During a period of mesopic vision, where both rods and cones work together under intermediate levels of illumination, the eye reaches its minimum threshold after about 40 minutes in the dark. At this time, our eyes begin to see in monochrome.

"Rods only give you a black and white image, but they're really sensitive," says Craig L. Blackwell, an ophthalmologist in Santa Cruz, California. "A single photon will fire off a cell response in a rod."

Of course, in order for the original photon to fire off a signal to the brain, it must hit the eye in the right place. The human eye has about 125 million hypersensitive rod cells, but hardly any of them reside in the center of the eye, Blackwell says. This explains why averted vision is so important to seeing detail in faint objects and also why color vision is largely compromised in the dark-adapted eye.

With a big enough telescope, however, color is not out of reach. The human eye is most sensitive to a wavelength of 550 nanometers, in the yellow-green part of the visual spectrum — near the peak wavelength of sunlight. While color vision varies from person to person, many observers report seeing greenish hues and, with a large enough aperture, even red in bright objects like the Orion Nebula (M42). The average human eye refreshes more than 60 times per second, limiting its ability to detect color or faint objects in the same way a camera that integrates data for a long period of time can.

But what the dark-adapted eye loses in color differentiation, it makes up for in dynamic range, or the ability to see both dim and bright objects in a single scene. In low-light conditions, the dynamic range is 15 magnitudes — at least 1 million to one.

"A camera will show it all, but cannot match the dynamic range of the human

SEE MORE: VISUAL OBSERVING TIPS

Use averted vision to allow light to reach the more sensitive part of your eye.

Tap your telescope (gently); motion can help you see more detail.

Sit. You'll be more stable, see more, and observe longer if you're not straining to get your view.

Slightly defocus a star; it can help make its color easier to detect.

Breathe deeply. Many beginners hold their breath while observing, but this is counterproductive; your visual acuity depends on a good flow of oxygen.

Dress in layers.

Avoid using your computer or looking at other bright lights for a couple hours before you begin observing.

Sketch your observations and/or take notes.

Drink caffeine; it may improve your night vision, although each person is different. It will, however, keep you more alert.

Use your dominant eye. You'll notice one of your eyes strains less and feels more natural when you look through a telescope.

Try higher magnifications; they'll help you pick out small, faint objects because their contrast against the sky background is higher.

Avoid alcohol while observing.

Use red goggles if you must look at a screen during your observing session, or use a dim red flashlight to consult your charts.

Use an eye patch to preserve your night vision in your observing eye or to block ambient light from your non-observing eye while you're looking through the eyepiece.

If you're lucky enough to have an observatory, you often may see a view like this one. It includes Jupiter, the Hyades, the Pleiades, Orion, and even the Orion Nebula (M42). Despite windy conditions and bright moonlight, the image came out fine. JOHN CHUMACK

eye," says Mark Wagner, an experienced visual observer in Northern California. "It's why a raw image will have a burned-out galaxy core, while the eye sees the bright core and dim arms simultaneously."

Anyone who has viewed M42 through a telescope will appreciate a range in detail — from the high-energy brilliance of the stars in the Trapezium cluster to the inky blacks of dark nebulosity — that will not appear in a raw image and that astroimagers can emulate only after hours of processing. "But it still sucks compared to the human eye," Wagner says.

M46 and NGC 2438

Sharpening our skills

As we age, our pupils don't open as widely as they used to, and the acuity of both rods and cones may decline. Unfortunately, there is no substantial evidence that connects carrots to improved vision; however, Ivester may have been onto something with his 18,260 pounds of carrots: "One of the earliest findings with vitamin A deficiency is night blindness," Blackwell says. The vitamin is essential to the production of photopigments, including rhodopsin, which is what rods need to absorb green-blue light. A lack of vitamin A creates a deficit in this pigment. While vitamin A deficiency is not common in the United States, it's prevalent in parts of Africa and Southeast Asia.

But the art of visual observing is only partly dependent on sharp vision. A person with perfect vision may not pick up on the mottled texture or filamentary details of the Crab Nebula (M1), and a skilled visual observer often can find objects through her 4-inch telescope that a casual observer using an 8-inch scope cannot.

Becoming a visual observer is a skill acquired during the time an amateur astronomer spends at the eyepiece. "When first attempting to observe a faint deep-sky object, you'll see little, if any, detail," Ivester says. "The more time you spend looking at an object, trying different eyepieces, using averted vision, the fainter the details that will begin to emerge."

It takes patience, diligence, and deep concentration — the latter of which Ivester finds comes naturally if he's observing alone in his backyard with the sounds of the North Carolina night in the air. It may take a few carrots, too.

This photo taken at Miramar, Argentina, shows the constellation Orion setting in the west while a Full Moon shone behind the observer. It illuminated both the sky and the landscape, showing that even bright nights can be good ones. LUIS ARGERICH

Where are the **women** in amateur astronomy?

Few women seem to participate in our hobby, but those who do are having the time of their lives.

by Karen Jennings

"Are you here with your husband?"

It's an innocent enough question. What's the big deal? Last summer, I walked through an observation field at a star party, noticed a beautifully built amateur telescope, and stopped to ask the owner what the aperture and focal ratio were. In a slightly patronizing tone, he asked, "Are you here with your husband?" I thought, "What does that have to do with the price of tea in China?"

Then he laughed, "I'm sorry," he said, "I just don't think a woman has ever asked me about my focal ratios before."

"There's a first time for everything," I said and made my way to the vendor tents. Five minutes later, as I'm drooling over an eyepiece that costs more than a year's college tuition, the vendor asks, "Are you here with your husband?"

Do people ask men attending similar events, "Are you here with your wife?" in the same manner? Attendees treat women amateur astronomers as the exception to the male rule at such events. If a woman knows something about astronomy, some people assume she must have picked it up from her husband. But then, after taking a moment, I looked around and noticed that I was one of the only female attendees at the event. Where are the women?

Star parties should attract equal numbers of men and women. Unfortunately, this isn't the case. MIGUEL CLARO

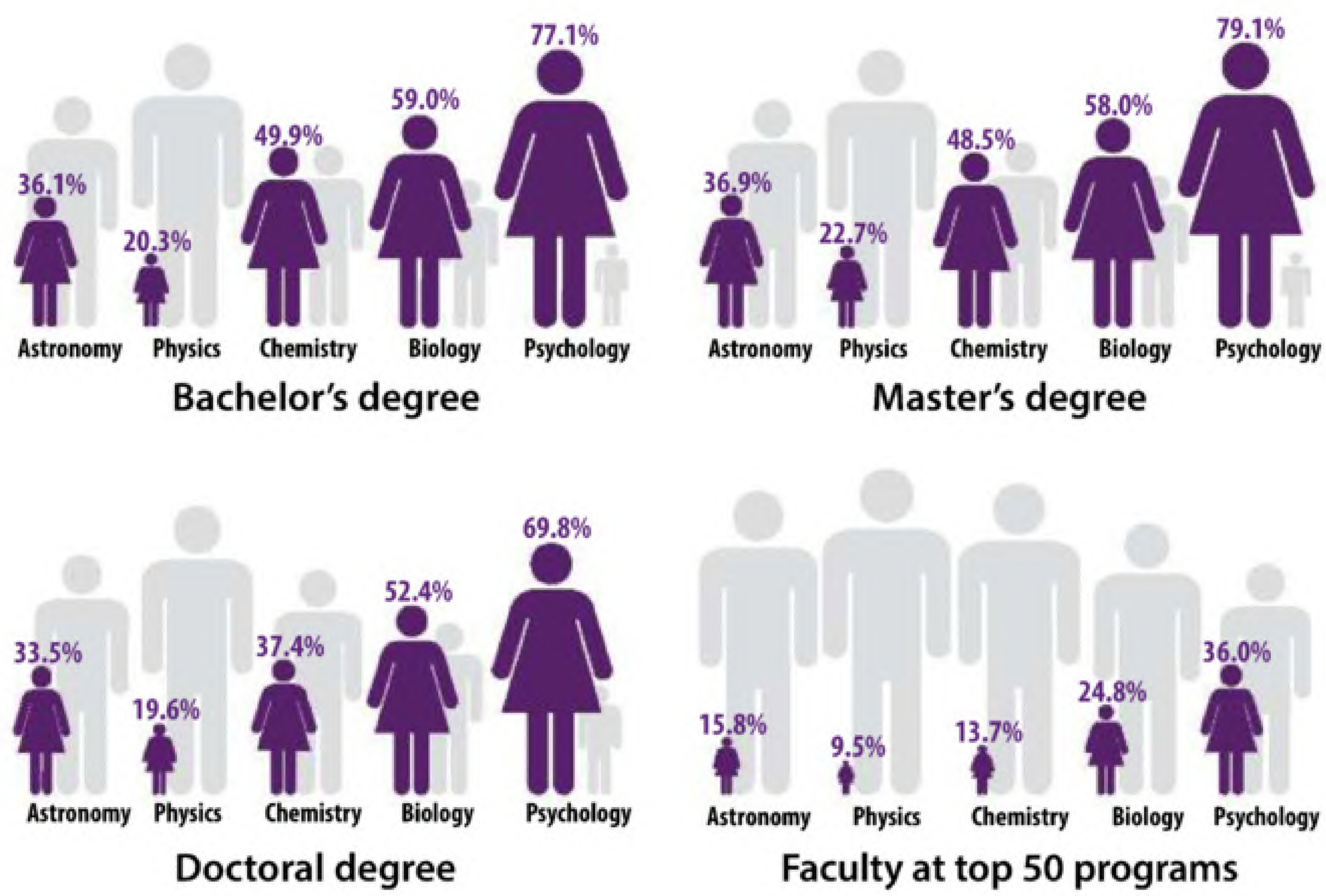
It's a hard question with lots of variables to tease through, and it has no easy answer. Does the obvious gender gap in the amateur astronomy community reflect a lack of interest or lack of ambition to engage in a male-dominated hobby? I doubt it. Women are interested in science.

Choice vs. gender bias

According to the 2011 study "Focus On: Female Students in High School Physics" conducted by S. W. Tesfaye, more girls are choosing physics classes in high school. Also that same year, another study showed that the percentage of women earning bachelor's degrees and doctorates in astronomy is increasing. The following year, research by Corinne A. Moss-Racusin at

BACKGROUND IMAGE: TANJA SUND

WHERE ARE THE WOMEN?



Three comparisons, tabulated in 2010 by the National Center for Science and Engineering Statistics, show that women earn more than half of all biology and psychology degrees. The number of astronomy and physics degrees they receive, however, lags far behind. There may be a correlation between the number of female professors (shown in the fourth comparison from Nelson Diversity Surveys, 2007, which only compiled data from the 40 top programs for astronomy [50 for other sciences]) and less women studying college astronomy and physics. However, biology and psychology departments also have fewer women as faculty, and that doesn't seem to affect the gender ratios. The percentages shown in this diagram coincide with the symbols' heights, not areas. ASTRONOMY: LIZ KRUESI AND JAY SMITH

Photographer Shannon Bileski of Winnipeg, Canada, enjoys shooting the northern lights. In this image, she captured stars, clouds, the aurora, and a bright meteor. SHANNON BILESKI

Yale University showed that physicists, chemists, and biologists are more likely to view male scientists more favorably than a woman with the exact same qualifications.

Do we find this kind of gender bias in the amateur astronomy community? Absolutely. Gender role stereotypes can be subtle, but they are pervasive and deeply rooted in our culture.

Assuming the reason that women are underrepresented in the amateur astronomy community is due to an inherent dislike or lack of interest in science, technology, and math is wrong. It's also gender discrimination in action. Many studies — including a highly publicized report by the National Academy of Sciences in 2012 — have discredited the idea.

Barriers to overcome

Are there obstacles? Sure. Women are disproportionately more likely than men to carry the bulk of child care and household responsibilities. We need to ask if star parties are child friendly. Do astronomy clubs offer child care or other support that would allow mothers to participate in meetings, stargaze late into the night, or staff public outreach events?

I became active with the Astronomy Foundation and began using its social media page to ask the question "Where are the women?" to start this conversation. I received many responses from men who recognize the issue and who actively work within their own astronomy clubs as well as national organizations to help transcend traditional gender roles and encourage participation by more women.

Through this process, I also had the privilege of interviewing more than 40 amazing female amateur astronomers from all over the globe. These role models should inspire a change in perspective in this male-dominated hobby.

Jeanette Lamb, astroimager, Australia

Jeanette Lamb was inspired to enter the hobby when her boys were learning about astronomy in primary school. A volunteer brought in a telescope and invited students to stargaze while giving a tour of the night sky. "That was it, one look at the globular cluster Omega Centauri (NGC 5139), and I was hooked," she says. Eight years later, Lamb is a well-respected astrophotographer with an impressive body of work.

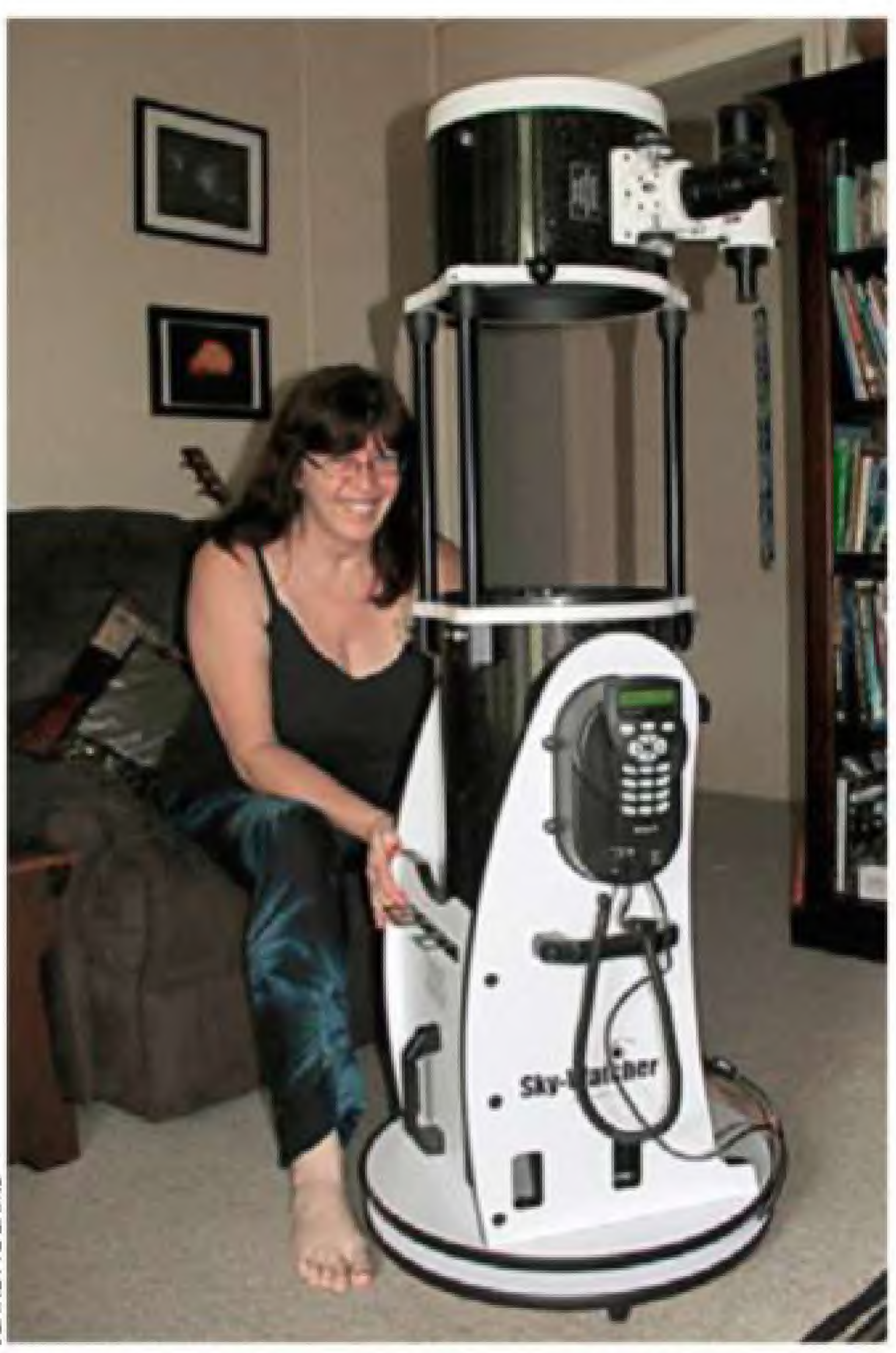
"I bought my dream scope a couple of months ago," Lamb says. "It's a Takahashi FS-78 refractor, with a field-flattener/reducer. I'm looking forward to winter so I can image all of those big nebulae in Sagittarius. My workhorse telescope is a 5-inch Explore Scientific ED127 refractor. I've used it for planetary observing, for which I add a 4x Tele Vue Powermate, and also for deep-sky work."

Lamb uses a highly modified Canon camera to capture solar, lunar, and planetary images through her telescopes as well as an off-the-shelf Canon 550D DSLR to capture wide-field shots of the night sky.

Is gender bias getting in the way of finding mentorship? Lamb remembers her early days as a novice, posting astroimaging questions on amateur astronomy forums that went unanswered while the male beginners with similar questions received responses and guidance. Largely self-taught, Lamb was able to navigate through what she calls the "boys' club" attitudes and found support and encouragement from like-minded male astrophotographers.

Karen Jennings *is a dedicated amateur astronomer, writer, and artist living in Delaware with her two sons.*

This image of the Silver Coin Galaxy (NGC 253) required 3 hours and 30 minutes of exposures. JEANETTE LAMB



JEANETTE LAMB

Jeanette Lamb became enamored with astroimaging when an amateur astronomer conducted an observing session at the school her sons attended.

A high-quality image of the Rho Ophiuchi region reveals emission, reflection, and dark nebulae, along with bright stars and even globular cluster M4. West is up in this image. JEANETTE LAMB

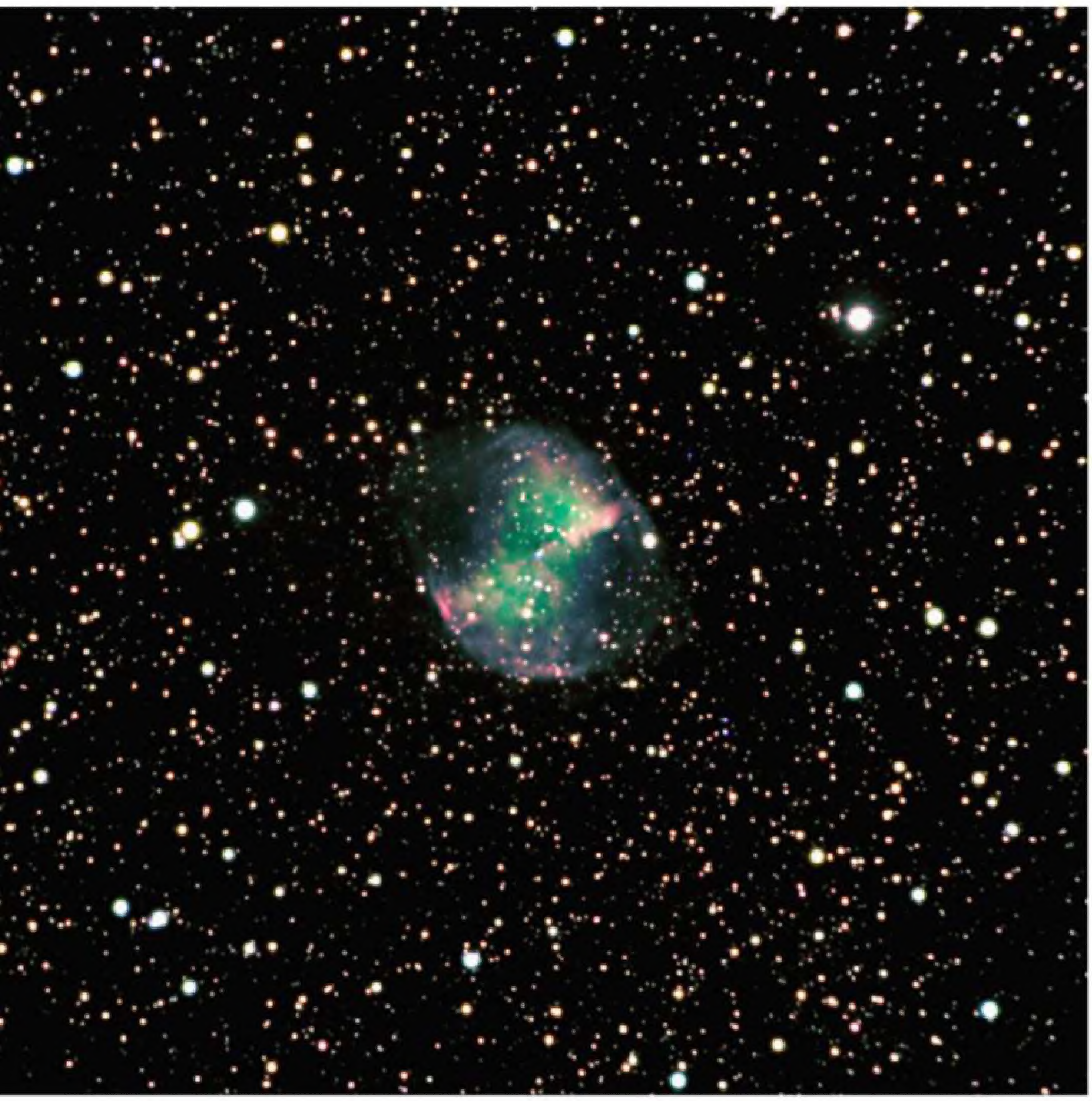
"I think I have gained a fair bit of respect in the community now," she says. "I still get the occasional patronizing comment, but now I ignore it. If I'm in a bad mood, I'll just ask them where their photos are hanging right now." Lamb noticed how some hobbyists viewed women amateur astronomers as novelties but says there has been improvement in recent years. "I would often refer to female astronomers using the analogy of the Waltzing Bears. It's not how gracefully we dance, it's the fact that we can dance at all."

Lamb encourages more women to become involved in amateur astronomy. "That's tough, though, because a lot of women, especially single mothers, just don't have the time to indulge in hobbies such as this," she says. "With work, children, and a house to keep, at the end of the day it's understandable that they just want to kick back and relax — not head outside into a cold backyard at night. But if we share our photos on social media, it might spark some interest and encourage them to step outside and look up."

Barbara Harris, astrometrist and photometrist, Florida

Barbara Harris' interest in astronomy developed in high school while taking courses in physics and Greek mythology. "Many of the myths would end with characters being placed among the heavens," she says. "I would want to go out and look at the sky and find the constellation associated with that myth." Harris was fortunate

► Barbara Harris really got into the hobby after she completed medical school. Her primary focus is to collect data that professional astronomers use in their research.
BARBARA HARRIS



▼ The Dumbbell Nebula (M27), a large planetary nebula in the constellation Vulpecula, is a favorite target for astroimagers of either gender.
BARBARA HARRIS

to have a physics teacher, who was also an amateur astronomer, bring his telescope to school for stargazing sessions.

Harris' astronomical interests grew after completing medical school. "Although I enjoy casually looking at the night sky, most of my activity is aimed at gathering scientific data that professional astronomers use," she says.

That data include photometry (measuring and monitoring brightnesses) of stars, astrometry (measuring positions) of asteroids, asteroid occultations (when an asteroid moves in front of a star and briefly blocks the light from that star), and hunting new meteor showers.

She identifies a problem with women getting active in the amateur astronomy community. "If you visit any astronomy club around the country," she says, "you will see that most of the membership is composed of white men. There are very few minorities and women in these clubs. It is not due to the club members. All of the amateur astronomers that I have met have been very welcoming and inviting. Many amateur astronomers are happy to share their hobby and invite others to learn about the skies." Harris believes that if girls are exposed to astronomy at a younger age, like in elementary and middle school, they may enjoy it and get more involved with it.

Erika Rix, astrosketcher, Texas

Erika Rix is deeply involved with the amateur astronomy community. She's the astrosketching columnist for *Astronomy* and co-author of two astronomical sketching books. She also freelance writes for other astronomy publications and gives astronomy presentations and workshops.

"Outreach is very important to me, especially for school functions and with my astronomy club, the Austin Astronomical Society (AAS)," Rix says. "I'm the newsletter editor for the AAS and volunteer as an administrator for the online forum 'Cloudy Nights Telescope Reviews.'"

Rix feels that it's important to encourage more women to participate in the amateur astronomy community. Her view is that professions and hobbies don't have to be stereotyped, and the more women lead the way, the better chance we'll have to spark an interest in science and math for young girls. "We can all be role models if we're willing to step forward," she says.

Does she feel that her gender played a role in how she was received in the amateur astronomy community? "Several times," she says. "At the first star party I attended, a few of the club members that hosted it assumed that I simply tagged along so that my husband could stargaze. It surprised them when I explained I had my own gear and then proceeded to set it up myself.

"The second time was at an astronomy show — funny enough, I was one of the presenters that year — where a vendor talked down to me as if I were wasting his time while inquiring about a telescope. It was obvious my gender played a role in that. I was a serious buyer, and he lost a sale that day. For the most part, though, I'm accepted as an amateur astronomer with no sway with regards to gender — or at least not that I'm aware of. I'm treated well and as an equal."

Erika Rix (right) loves to capture celestial objects through sketching and to teach others her techniques. Above, Rix captured Hercules Crater and Atlas Crater on the waning gibbous Moon's terminator with this dramatic sketch. ERIKA RIX

▲ Amateur astronomer Erika Rix seeks out venues to be a goodwill ambassador for our hobby. ERICA RIX

◄ Kathryn Gray spends hours comparing images taken minutes, hours, or days apart looking for anomalies in deep-sky objects. PAUL GRAY

▼ Kathryn Gray shakes hands with Apollo 11 astronaut Neil Armstrong as fellow space-travelers Bill Anders, Victor Gorbakto, and Jim Lovell look on. STARMUS/MAX ALEXANDER

Kathryn Aurora Gray, supernova hunter, Canada

The future may be a bit brighter. Take, for example, Kathryn Aurora Gray. At the ripe old age of 10, she discovered a magnitude 17 supernova in UGC 3378, a galaxy in the faint northern constellation Camelopardalis, on January 2, 2011.

Kathryn's stellar discovery, assisted by amateur astronomers Paul Gray (her father) and David Lane, distinguishes her as the youngest female to discover a supernova. Now age 13, Kathryn has rubbed elbows with astronauts Neil Armstrong and Jim Lovell celebrating her explosive stellar accomplishments.

Indeed, with role models like the ones I've featured here, amateur astronomy hopefully will see a renewed interest by women around the world.

10 top winter binocular treats

When it's too cold to set up your telescope, get your sky-fix by grabbing your binoculars. **by Phil Harrington**

There are more spectacular targets to see through binoculars in winter than probably any other season. Think about it. We have the Orion Nebula (M42), the Pleiades (M45), the Hyades, and a host of other star clusters, nebulae, and colorful stars from which to choose. Wow!

We already have profiled many winter showpieces in previous binocular tours. This year, let's try for some tough targets that often go missed and unappreciated.

We begin high in the western sky with the **California Nebula** (NGC 1499) in the constellation Perseus the Hero. This emission nebula is easy to locate thanks to magnitude 4.0 Xi (ξ) Persei, just 0.8° to its south. But seeing the nebula, well, that's another matter. You'll need to move the star out of the field of view to have any hope of seeing the cloud's faint 2.5° long by 0.7° wide profile. A pair of Hydrogen-beta narrowband filters held carefully in front of the eyepieces of tripod-mounted binoculars will help you conquer this supreme test.

M78 in Orion is the sky's brightest reflection nebula. Binoculars will bring it into view if your sky is dark enough. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

Now head east from Perseus into Auriga the Charioteer. This star pattern is well-known for three spectacular binocular clusters: M36, M37, and M38. It's always fun to view all three, but let's also look around and see what else is in the area.

Can you spot open cluster **NGC 1893**? Never heard of it? NGC 1893, which glows at magnitude 7.5, is in the same field of view as M36 and M38, just 2.7° to the latter's south-southwest.

Through my 10x50 binos, I can make it out as a faint glow peppered with four stars that many say resemble the letter Y. Images show that IC 410, a large emission nebula, engulfs these stars. Unfortunately, normal-size binoculars have no hope of showing this cloud of glowing hydrogen that spawned the cluster.

But wait, there's more. We also have open cluster **NGC 1907**, just a Full Moon's width (0.5°) to the south of M38. Binoculars show only a hint of the cluster because none of its stars shines brighter than 10th magnitude. Collectively, however, they create a 5'-wide magnitude 8.2 target that's within reach of my 10x50 binoculars on clear moonless nights.

Moving due south from the Charioteer, we next visit Orion, where you'll find **M78**. This small tuft of reflection nebulosity lies about 3.7° — or a little more than half the field of view of 7x50 binoculars — east of magnitude 2.3 Mintaka (Delta [δ] Orionis), the top star in the Hunter's belt. Like the Orion Nebula, M78 belongs to a vast expanse of hydrogen that astronomers call the Orion Molecular Cloud.

M78 is a great test of a winter sky's quality. Peering through a suburban sky, my

NGC 2169 is sometimes called the 37 Cluster because the two groupings of its stars give the appearance of those numerals. MARTIN C. GERMANO

10x50 binoculars barely show it as a dim blur. But under darker skies, M78 is much more obvious through the same optics. The oval cloud reminds many of a faint comet, with an embedded pair of 10th-magnitude stars serving as the "nucleus."

Stay in Orion, but now head about a binocular field north of Betelgeuse (Alpha [α] Orionis). There you'll find open cluster **NGC 2169**. Look for it to the southeast of the midpoint between magnitude 4.4 Nu (ν) and magnitude 4.5 Xi Orionis. This small and, at magnitude 5.9, relatively bright open cluster is made up of about 30 stars ranging from magnitudes 8 to 10. Binoculars resolve the four brightest cluster members buried in a small misty glow.

East of Orion is the large, empty expanse of Monoceros the Unicorn. The

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Phil Harrington *is an* Astronomy *contributing editor and author of* Cosmic Challenge *(Cambridge University Press, 2010).*

The California Nebula (NGC 1499) in the constellation Perseus covers more sky than eight Full Moons, resulting in a low surface brightness. You'll see it through binoculars only on the clearest moonless nights at an observing site far from city lights. JASON WARE

Milky Way passes through the region, so, while it lacks in bright stars, Monoceros offers many superb deep-sky targets. Aim toward Beta (β) Monocerotis, about halfway between Betelgeuse and Sirius (Alpha Canis Majoris), to find our next target, open cluster **NGC 2232**.

Many faint stars envelop the cluster's brightest star, 5th-magnitude 10 Monocerotis, in a curved cone-shaped pattern that opens toward the southeast. Because it sports an apparent diameter nearly equal to that of the Full Moon, NGC 2232 actually looks better through giant binoculars (those with front lenses larger than 70mm) than through most telescope/eyepiece combinations. The cluster's magnitude, 4.2, is impressive, but remember how much area it covers, and you'll understand why it's not a blazing spot in the sky.

From magnitude 3.9 Alpha Monocerotis, scan 8° east-southeast, crossing into Puppis, to find our next target, the **Dish Cluster** (NGC 2539). While its magnitude of 6.5 makes it a bit challenging to locate through binoculars, this open cluster is easy to observe once you find it.

Through my 10x50s, the light of the Dish Cluster's 50 suns blends into an ill-defined blotch of light just touching the unrelated magnitude 4.7 star 19 Puppis. (The star actually lies 12' east-southeast of NGC 2539's center.)

By switching to my 16x70s, I can begin to make out some of the Dish Cluster's true stars. The two brightest are a magnitude 9.1 red giant and a magnitude 9.6 orange giant. Can you make out their subtle colors through your binoculars?

Next, center on Sirius, and then shift 4.6° east-northeast to magnitude 4.1 Muliphein (Gamma [γ] Canis Majoris). Hop another 3.4° due east, and you'll come to open cluster **NGC 2360**.

NGC 2360 is also known as Caroline's Cluster after its discoverer, Caroline Herschel. She described it as "a beautiful cluster of pretty compressed stars near ½° in diameter." Eighty stars call this cluster home, although none is resolvable through most binoculars. Instead, we see a delicate blur of light shining at about 7th magnitude.

The next treat is more a test of your latitude than the quality of your sky. Northern observers will need a good view to the south to spot **NGC 2527** in Puppis. It resides 9° east of magnitude 2.5 Aludra (Eta [η] Canis Majoris). Some 40 suns inhabit this magnitude 6.5 open cluster. You'll see eight or nine, including an 8th-magnitude point lying on the group's eastern edge, through binoculars. They appear enveloped in the soft glow of the fainter cluster stars.

Our final target, **NGC 2571**, lies just 3.5° east-southeast of NGC 2527 and easily fits into the same field. Here, a collection of about two dozen 9th-magnitude suns blends to create a magnitude 7.0 tuft of celestial cotton framed inside a triangle of 7th-magnitude stars. If your binoculars magnify 11x or more, you should just be able to resolve some of the cluster's stars.

Once you spot these final two highlights in Puppis, be sure to explore the surrounding area. The eastern half of the constellation contains star clouds that are magical through binoculars.

I hope you enjoy these off-the-beaten-path objects that await you in our magnificent winter sky. And remember that two eyes are better than one.

EXPLORE MORE WINTER BINOCULAR TREATS AT **www.Astronomy.com/toc.**

ASTRO**SKETCHING**

BY ERIKA RIX

The feeling is mutual

Italian astronomer Galileo Galilei discovered Jupiter's four brightest moons in 1610. Because of his find, you'll often hear them called the Galilean satellites. Observers frequently see them passing in front of or disappearing behind the planet. But every six years near Jupiter's equinox, the orbital planes of these four moons tilt almost edge-on to Earth, and less common phenomena occur: The satellites eclipse and occult each other. Astronomers call these occurrences mutual events.

The next equinox occurs February 5, so sharpen those pencils. Ample opportunities exist through August 2015 to sketch the phenomena. To help you plan, the Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE) provides the dates, times, and types of mutual events for Jupiter's current apparition on their website at http://tinyurl.com/pn49lnh. In addition, *Astronomy* mentions a few each month in "The Sky this Month."

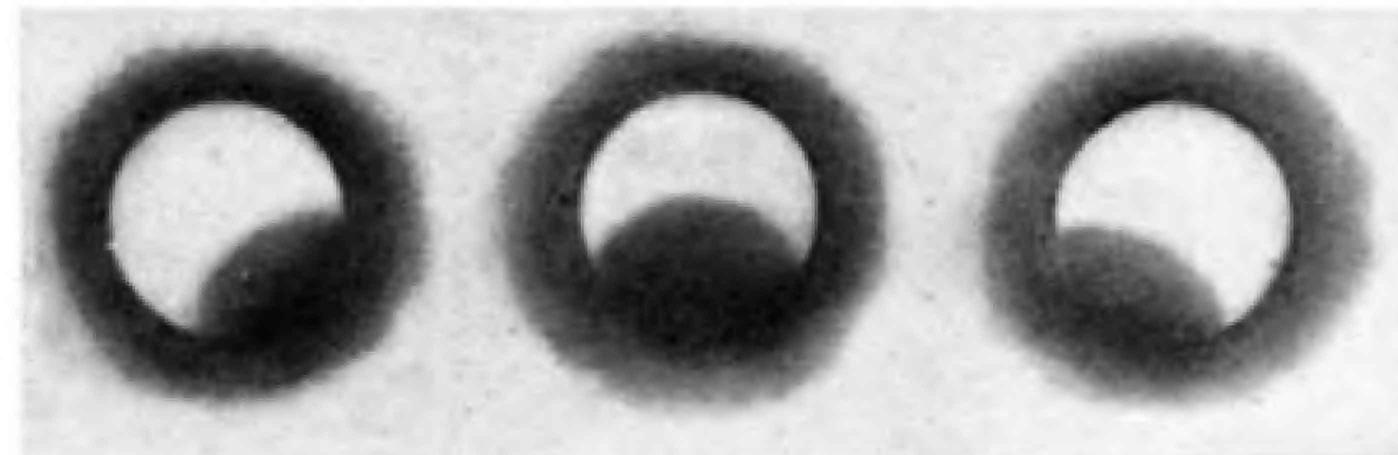
During a mutual occultation, two satellites approach each other and merge to form a brighter oblong image. That image then either dims as it rotates during a partial occultation or becomes circular during a total or annular occultation. It brightens once more just before the satellites separate and move away from each other.

When observing a mutual eclipse, you can't see the shadow approaching the second moon, so there's no warning of its beginning other than a dimming of the eclipsed satellite. Ephemerides may be off by a few minutes, so start your observation early. Once the event begins, estimate the brightness of the satellite being eclipsed at three stages: when it starts to decrease, when it stabilizes, and when it begins to increase. The easiest way to estimate a moon's magnitude is to compare it to similarly bright nearby stars viewed through your scope.

Although you can observe both types of events through a small telescope, you'll have difficulty noticing a change in brightness less than 20 percent during an eclipse with an aperture under 6 inches.

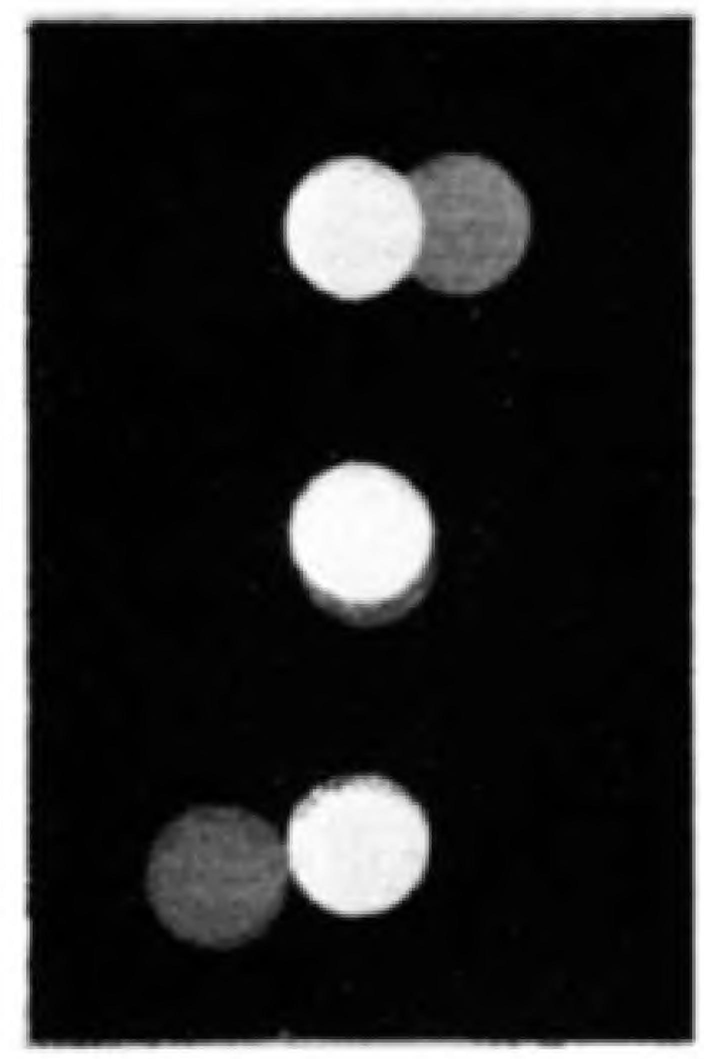
I've found the key to a skillful sketch sequence is preparation. Practice gauging brightnesses beforehand by making magnitude estimates of variable stars, and then formulate a game plan. Incorporating a voice recorder for notes frees up time you can use for sketching.

Prepare your brightness value estimates ahead of time by using a nearby Galilean moon for comparison. Identify satellites that will be in the vicinity to prevent unexpected distractions and to guarantee that you keep your eye on your target moon.



Eclipse of III by Shadow of IV
1932 *Feb.* 16. T. E. R. Phillips

1932 *Feb.* 18.
Ecl. of I by Shadow of IV B. M. Peek



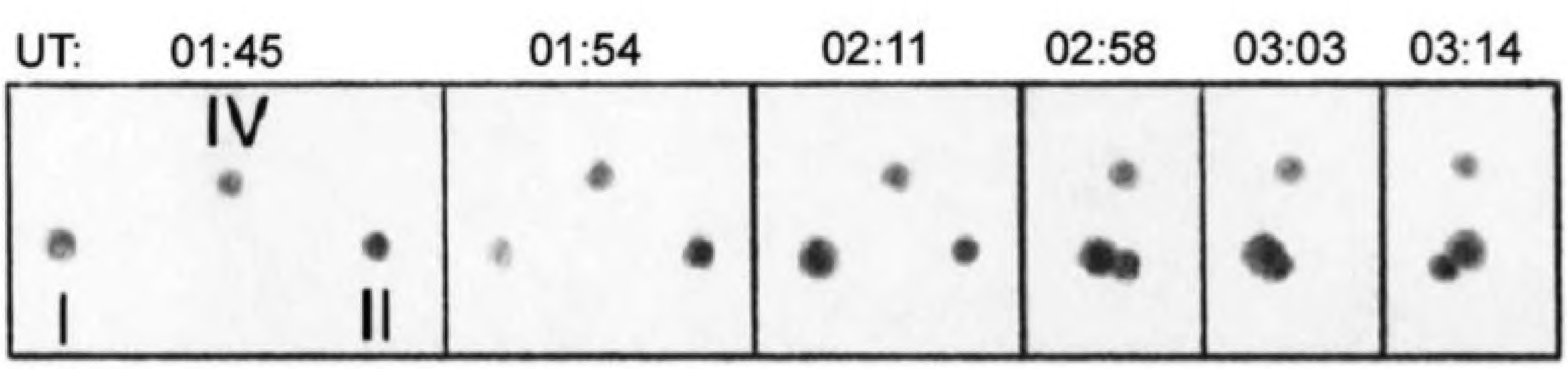
1932 *Mar.* 14.
Occ. of IV by I.
R. Schlumberger

These historical sketches show mutual events of Jupiter's satellites in early 1932. Drawings come from *Memoirs of the British Astronomical Association*. For the top image, the sketcher used an 8-inch refractor; for the image at lower left, the sketcher employed a 12¼-inch reflector; and the third image was made through a 9-inch refractor. COURTESY THE BRITISH ASTRONOMICAL ASSOCIATION

Try to complete a sketch every few minutes during the event. Record the times you began each sketch and the times for all brightness estimates within six seconds. Express them in Universal Time if you plan to share them.

The IMCCE uses visual observations and sketches for research and has additional material on its website. I encourage you to participate and also suggest forwarding your reports to organizations such as the Jupiter sections of the Association of Lunar and Planetary Observers and the British Astronomical Association. Both groups promote the study of mutual events.

Take advantage of this once-every-six-years opportunity. You'll find watching the dance of planetary satellites fascinating, and you'll create memories you actually can show people.



This series of sketches shows the January 12, 1991, mutual eclipse and occultation of Io (I) by Europa (II). It also shows Callisto (IV) in the same field of view. The sketcher used a 10-inch reflector. JOHN ROGERS

COMING IN OUR

NEXT ISSUE

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- Discover Orion's deep-sky gems
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Astronomy magazine

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4. Outside the mail	208	-0-
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h. Total (sum of 15f and g)	145,432	143,978
i. Percent paid (15c divided by 15f times 100)	99.75%	99.96%
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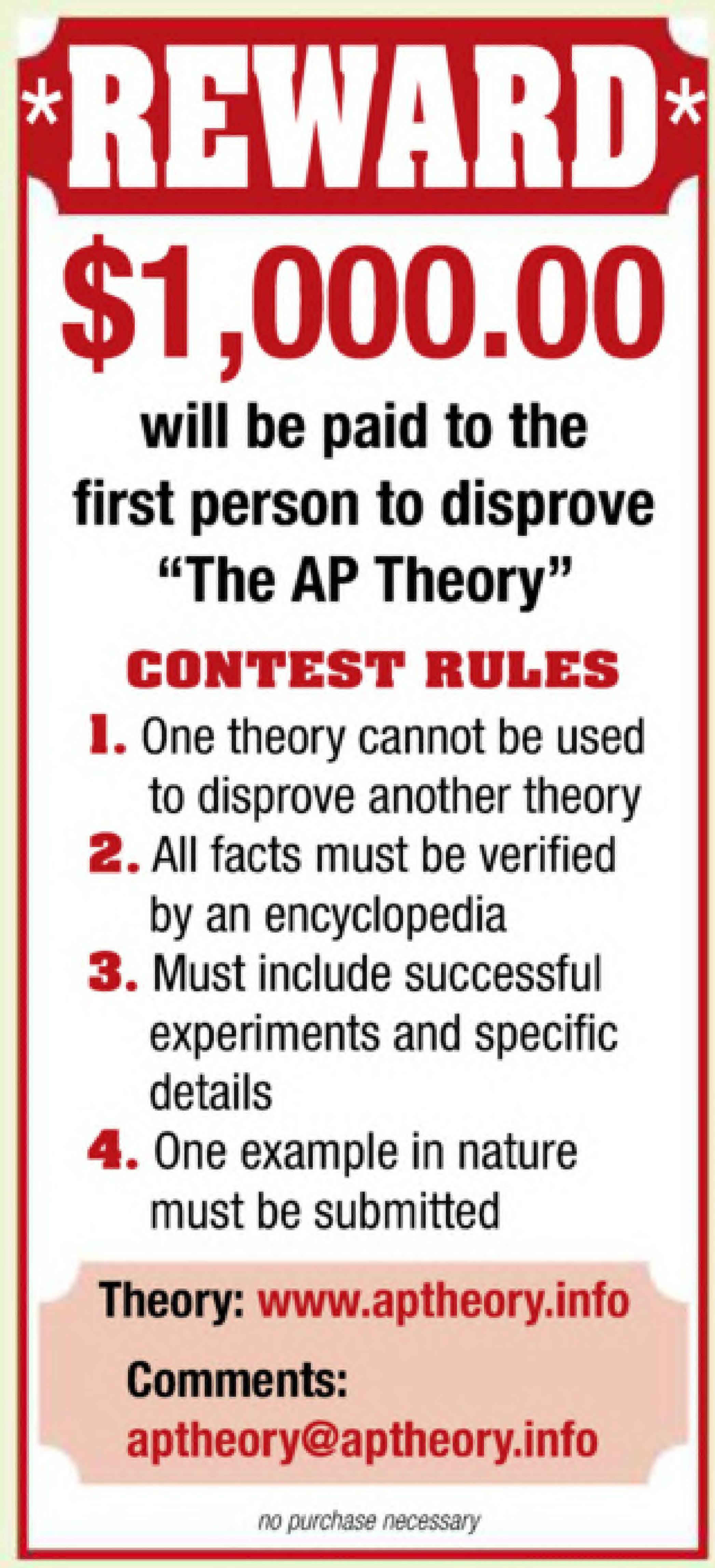
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READER GALLERY


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1. CELESTIAL ENCOUNTER
Comet Siding Spring (C/2013 A1) drifted past the spectacular globular cluster 47 Tucanae last August. Luckily, this imager was able to follow the whole encounter. (5.6-inch TEC-140 refractor at f/7.2, FLI Proline 16803 CCD camera; comet: LRGB image with exposures of 36, 24, 24, and 24 minutes, respectively; globular cluster: LRGB image with exposures of 120, 60, 60, and 60 minutes, respectively, taken August 30, 2014, from Coonabarabran, Australia) • ***Marco Lorenzi***


2


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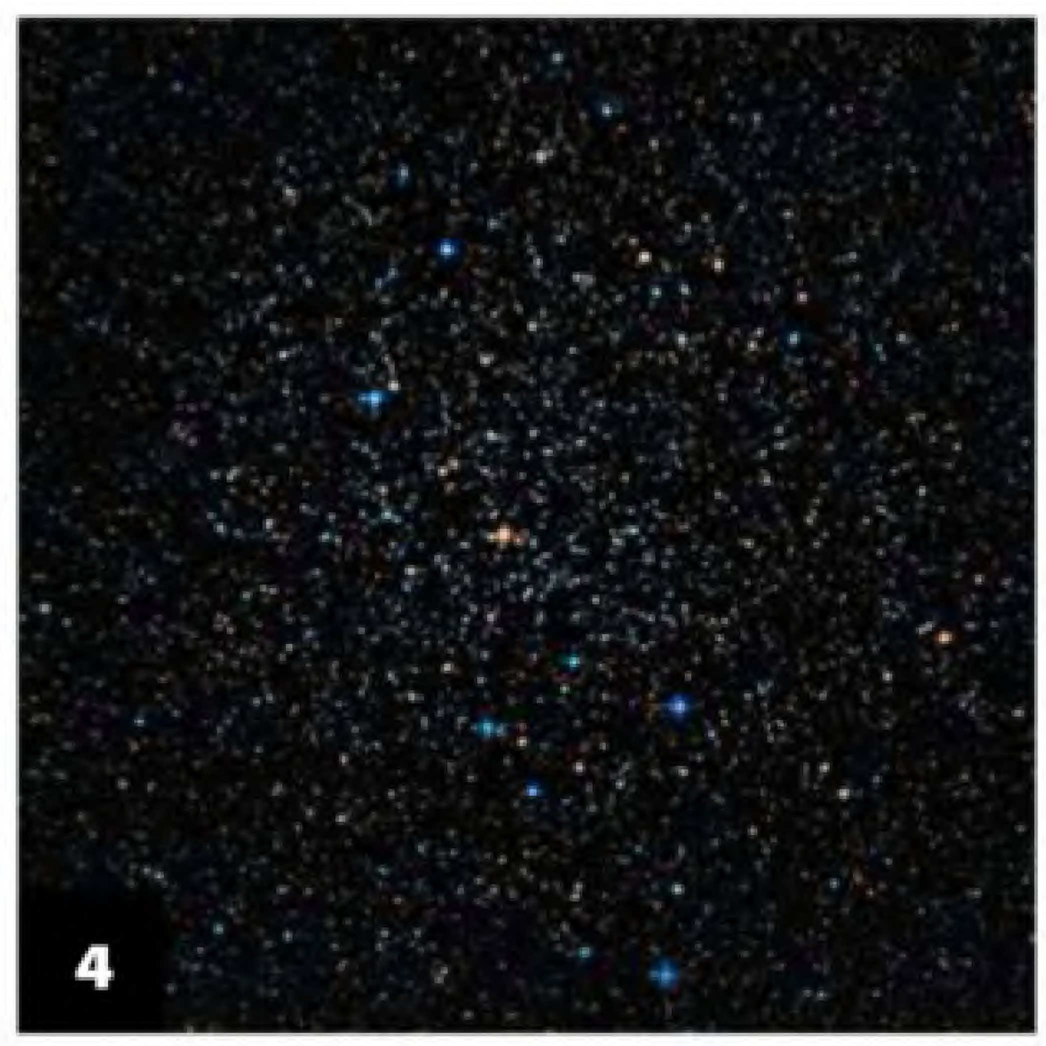
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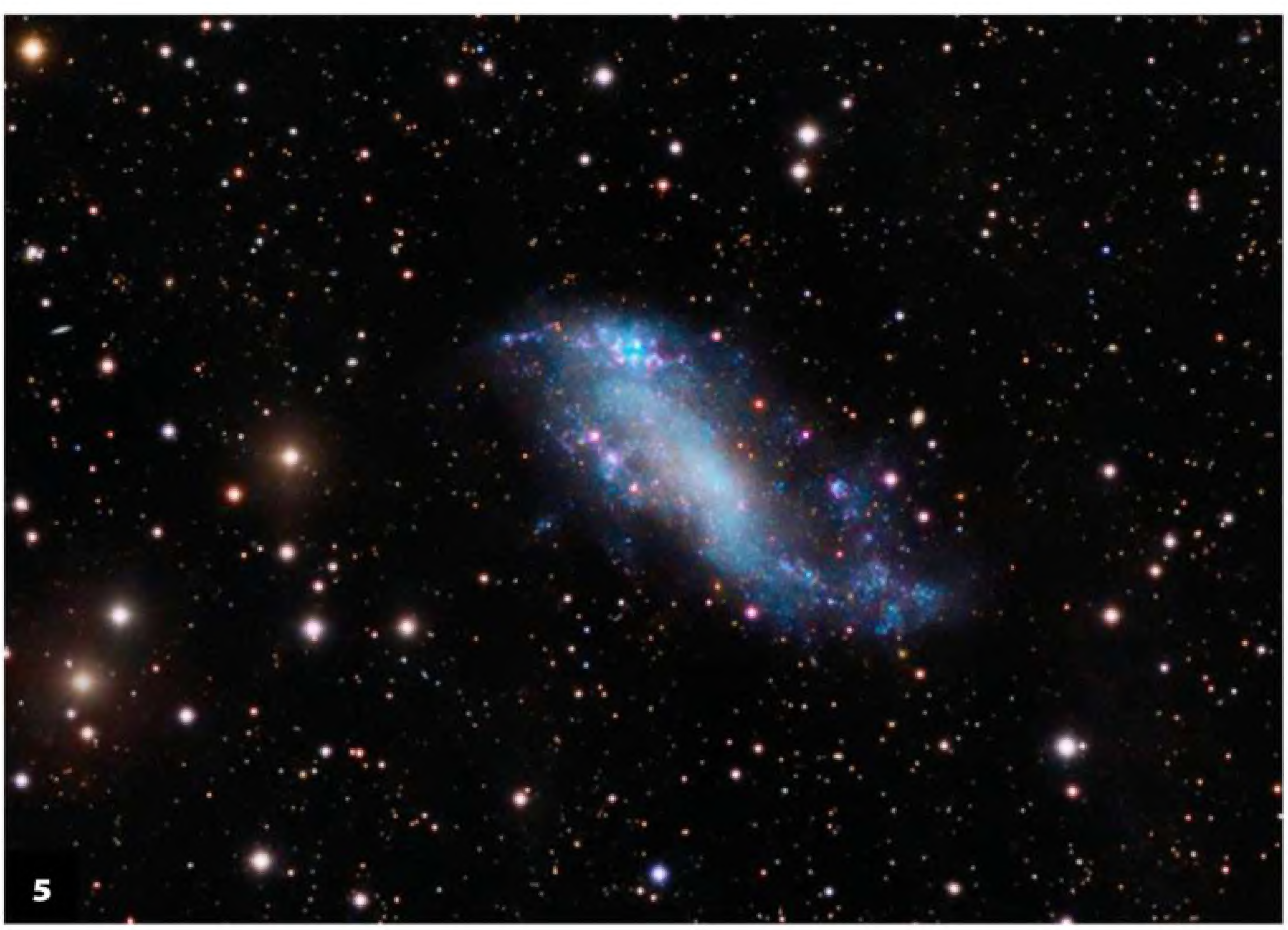
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2. CALL ME SNAKE
The Snake Nebula (Barnard 72) is the most apparent dark nebula here, but not the only one. The ultra-dark spot to the Snake's lower right is B68. B74 sits just above this image's second-brightest star, HIP 85242, which glows at magnitude 6.2. To its left, 44 Oph shines at magnitude 4.2. (3.6-inch Astro-Tech AT90EDT refractor at f/6.7, SBIG ST-8300M CCD camera, LRGB image with exposures of 120, 40, 40, and 40 minutes, respectively) • ***Dan Crowson***

3. COLORFUL CLOUD
IC 1871 is a small emission nebula that is part of the much larger Baby Nebula (IC 1848), which lies in the constellation Cassiopeia the Queen. IC 1871 lies just to the left of the Baby's "head." (10-inch Deep Sky Instruments RC10C Ritchey-Chrétien reflector at f/7.3, FLI ML-6303 CCD camera, Hα/OIII/SII image with exposures of 180, 90, and 90 minutes, respectively) • ***Behyar Bakhshandeh***

4. MOTHRA
NGC 6940 is an open cluster in the constellation Vulpecula the Fox. This dense group of stars also goes by the designations Melotte 232, Collinder 424, Lund 961, and Mothra, a name bestowed upon it by *Astronomy* Contributing Editor Stephen James O'Meara. (8-inch Explore Scientific PN 208/3.9 Newtonian Astrograph with Explore Scientific HR Coma Corrector to yield f/4.1, Canon XSi DSLR, ISO 800, sixty-five 1-minute exposures, stacked) • ***Chuck Kimball***

5. CODDINGTON'S NEBULA
Despite its proper name, IC 2574 is a galaxy in the constellation Ursa Major the Great Bear. Astronomers classify it as a weakly barred spiral that's also irregular in appearance. IC 2574 lies a scant 12 million light-years away, spans some 50,000 light-years, and glows at magnitude 10.4. (5.6-inch Telescope Engineering Company TEC-140 refractor at f/7, SBIG ST-8300M CCD camera, LRGB image with exposures of 520, 180, 180, and 180 minutes, respectively) • ***Bernard Miller***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.


ESO/DSS 2

Hole in the sky

Under a dark sky, you'll get a kick out of seeing a dark nebula through your telescope. Made of tiny grains of dust, dark nebulae stand out because their volume is large and they block light from stars and other objects beyond them. Such is the case with Lupus 4, a dark cloud in the southern sky, imaged here with the 2.2-meter telescope at the European Southern Observatory's La Silla Observatory in Chile.

Lupus 4 lies some 400 light-years away, and it is associated with a star cluster called the Scorpius-Centaurus OB Association. This young group of hot stars finds itself intertwined with remnants of dust like Lupus 4, which contains a denser concentration of material near its center than at the edges, suggesting it may trigger star formation in the future. In that case, intense radiation of infant stars will illuminate the dust and perhaps sculpt it into new shapes.

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Astronomy's 2015 Guide to the Night Sky

LUNAR PHASES

New	First	Full	Last
		Jan. 4	Jan. 13
Jan. 20	Jan. 26	Feb. 3	Feb. 11
Feb. 18	Feb. 25	March 5	March 13
March 20	March 27	April 4	April 11
April 18	April 25	May 3	May 11
May 18	May 25	June 2	June 9
June 16	June 24	July 1	July 8
July 15	July 24	July 31	Aug. 6
Aug. 14	Aug. 22	Aug. 29	Sept. 5
Sept. 13	Sept. 21	Sept. 27	Oct. 4
Oct. 12	Oct. 20	Oct. 27	Nov. 3
Nov. 11	Nov. 19	Nov. 25	Dec. 3
Dec. 11	Dec. 18	Dec. 25	

All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best time to observe our satellite through a telescope comes a few days on either side of its two quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/Arizona State University

VENUS spends the first several months of 2015 in the evening sky. At its peak in early June, the brilliant planet climbs some 25° high in the west an hour after sunset. It has a spectacular conjunction with Jupiter on June 30 and July 1, when the two beacons lie within 1° of each other. After passing between the Sun and Earth in mid-August, Venus returns to view before dawn. It joins in another spectacular grouping, this time with Mars and Jupiter, during October. NASA

JUPITER always shows a dynamic face. Its atmosphere displays an alternating series of bright zones and darker belts pocked by the Great Red Spot. Even through a small telescope, the planet's four big moons appear conspicuous. You often will see them change positions dramatically during the course of a single night. Jupiter reaches its peak in early February, when it shines brightest (magnitude –2.6) and looms largest (45" across), though it's a fine sight through July and again from October until year's end. NASA/JPL/USGS

SATURN and its rings provide a spectacular attraction for telescope owners during most of 2015. The ringed world is on display from January through October and again in late December, but it appears best around the time of opposition in May. Saturn then shines at magnitude 0.0 and measures 19" across, while the rings span 42"and tilt 24° to our line of sight. Even a small telescope reveals the dark, broad Cassini Division that separates the outer A ring from the brighter B ring. NASA/ESA/STScI

WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven brightest stars form a distinctive hourglass pattern. The bright blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.
The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.
The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.
M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.
Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.

SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the Dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star. From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.
M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.
The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.
M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.

Star maps by *Astronomy*: Roen Kelly

Jan. 14 Mercury eastern elongati

Feb. 6 Jupiter is

March 20 Total

April 4 Total lun

April 22 Lyrid m peaks

May 7 Mercury eastern elongati

May 22 Saturn

June 6 Venus is eastern elongati

July 1 Venus pa of Jupiter

July 6 Pluto is a

Aug. 13 Perseic peaks

Aug. 31 Neptun

Sept. 27 Total l

Oct. 11 Uranus

Oct. 15 Mercury western elongat

Oct. 17 Mars pa of Jupiter

Oct. 21 Orionid peaks

Oct. 26 Venus is western elongat

Oct. 26 Venus p of Jupiter

Nov. 3 Venus pa of Mars

Nov. 17 Leonid peaks

Dec. 14 Gemini peaks

Open cluster
Globular clus
Diffuse nebu
Planetary nel
Galaxy

y is at greatest
on

s at opposition

solar eclipse

nar eclipse

neteor shower

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on

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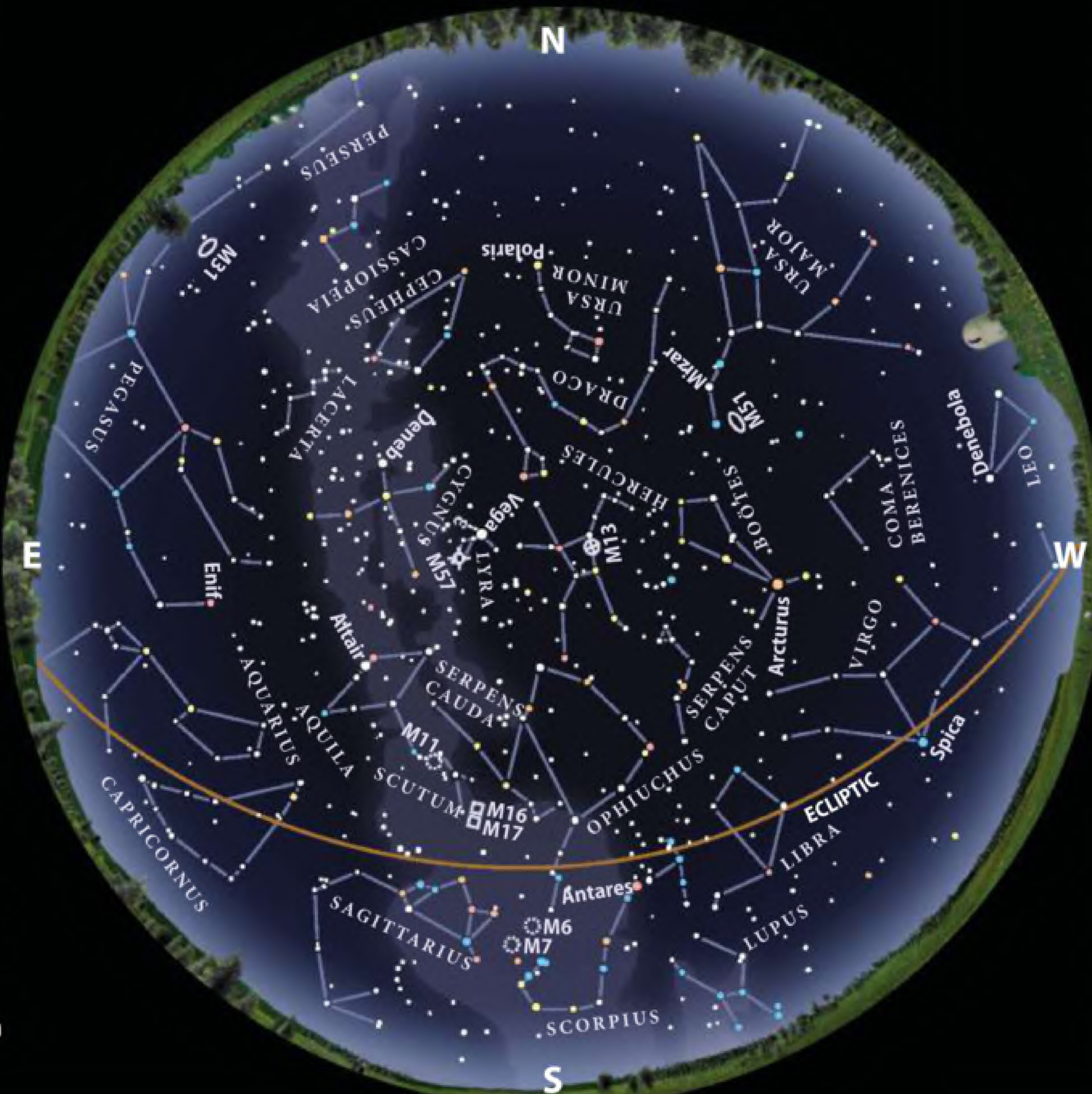


SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius lies Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

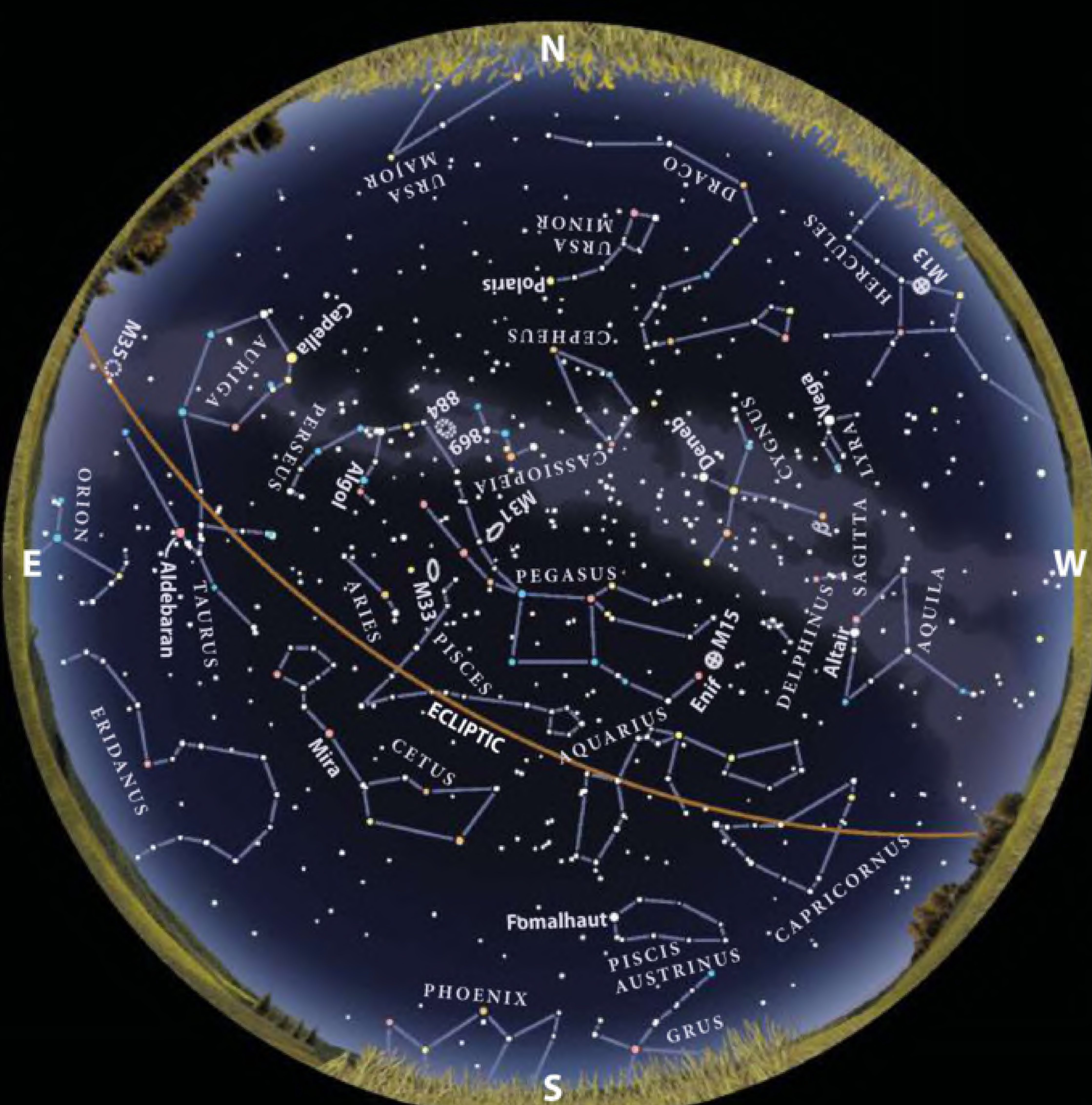
Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.



AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern United States, it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

Deep-sky highlights

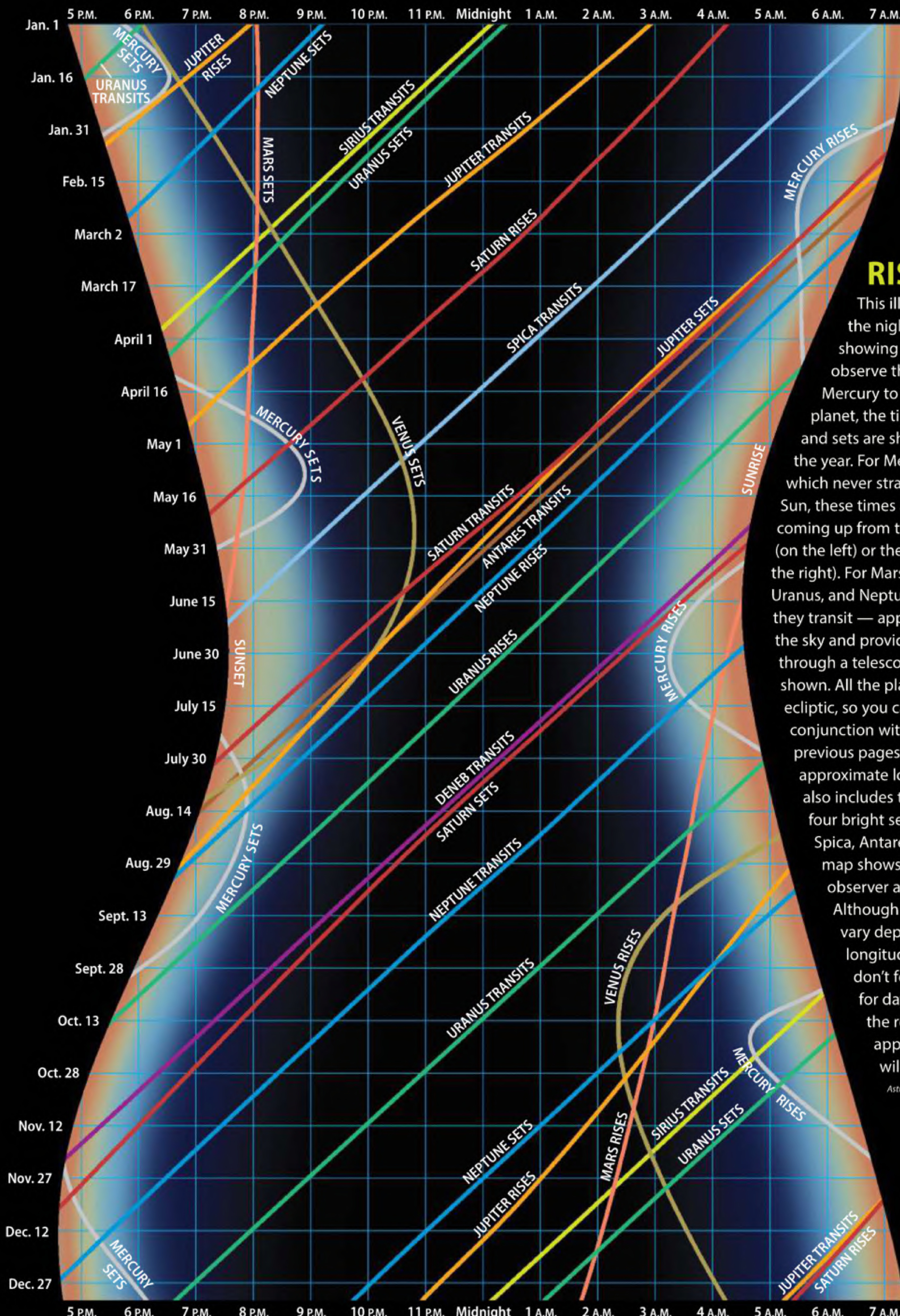
The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.

Astronomy magazine



RISE & SET

This illustration presents the night sky for 2015, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

Astronomy: Rick Johnson

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

March 2015: Dueling planets

March sees the two brightest planets — Venus and Jupiter — dominate the evening sky. **Venus**, the brighter of the two at magnitude –3.9, looks dazzling in the west-northwest as twilight deepens. Although it is drawing slowly away from the Sun, the brilliant planet still sets before total darkness settles in. Be sure to look on the evenings of March 22 and 23 when a waxing crescent Moon appears nearby.

When viewed through a telescope, Venus likely will prove disappointing. The planet's disk measures just 13" across in mid-March and displays a fat gibbous phase. Views will improve significantly later this autumn and winter as Venus climbs higher and comes closer to Earth.

Venus had a close conjunction with **Mars** in February and, although the two planets are now drifting apart, Venus continues to be your best guide for finding the Red Planet. Use binoculars to scan for magnitude 1.3 Mars to the lower left of its brilliant sibling. The ruddy world sets about an hour after the Sun, but you'll want to start searching for it some 30 minutes sooner. Mars' low altitude and tiny disk (just 4" in diameter) make it a disappointing telescopic object.

Unlike Venus and Mars, which dive below the horizon while the night is still young, **Jupiter** blazes away from dusk until the wee hours. The giant planet stands in the northeast as darkness falls and climbs highest in the north before midnight local time. It shines at magnitude –2.4, more than 200 times brighter than any star in its host constellation, Cancer the Crab.

Now just a month removed from opposition and peak visibility, Jupiter remains a stunning sight through any telescope. The best views will come in late evening when it lies farthest above the horizon and its light passes through less of Earth's atmosphere. The planet's 43"-diameter disk shows stunning detail even through small scopes and provides a thrill to experienced and novice observers alike. During moments of good seeing, when turbulence in our atmosphere dies down, the jovian cloud tops explode with detail. You'll also want to follow the motions of Jupiter's four bright Galilean moons as they change positions from night to night.

Saturn rises before midnight local time and climbs high in the northeast by the time twilight begins. The magnitude 0.4 ringed planet adorns the lovely star pattern of Scorpius the Scorpion just 2° from the bright star Beta (β) Scorpii. Saturn is currently in the midst of an unusually long period, which lasts from January to May, within this constellation. Planets don't normally spend much time in Scorpius because its borders, defined by the International Astronomical Union, include only a tiny part of the planet's orbital path.

Saturn nearly always tops the list of favorite observing targets. March should be no exception. The planet's ring system spans 39" and tilts 25° to our line of sight, affording magnificent views of its structure. Look in particular for the Cassini Division, the dark gap that separates the outer A ring from the brighter B ring.

The first half of March sees the continuation of **Mercury**'s finest morning appearance of 2015. On the 1st, it rises more than two hours earlier than the Sun and climbs nearly 15° high in the east an hour before sunrise. Mercury also shines brightly, at magnitude 0.0, so it stands out in the predawn twilight. Through a telescope, the innermost planet shows a disk 7" across that appears nearly two-thirds illuminated.

The starry sky

March evenings find Crux the Cross to the left of the South Celestial Pole. Around 8 P.M. local time in mid-March, Crux and the pole are at the same altitude. This month, let's follow a path from the Cross to the pole and stop at some attractive features along the way.

We'll begin our journey at 1st-magnitude Acrux (Alpha [α] Crucis), the Cross' southernmost star. Through a telescope, this luminary resolves into two components of nearly equal brightness located a mere 4" apart. They look spectacular on nights with excellent seeing, especially through a good refracting telescope.

Just to the right of Acrux lies Musca the Fly. Although small, this constellation appears quite prominent. Move less than 1° along the line from Delta (δ) to Beta Muscae and you'll find the nice globular cluster NGC 4833. You can start to resolve this globular cluster through a 10-centimeter instrument.

The sky becomes more desolate as you continue moving toward the pole and away from the Milky Way. We next enter Chamaeleon, a constellation that started appearing on celestial charts and globes near the beginning of the 17th century. Dutch navigators Pieter Keyser and Frederick de Houtman, who first introduced this grouping, probably were inspired to place a chameleon in the sky because of the number of these delightful creatures they found on Madagascar.

Although few easy telescopic objects reside in Chamaeleon, it's worth looking for IC 2631. This reflection nebula surrounds a 9th-magnitude star near the constellation's border with Carina the Keel. It forms a nearly perfect equilateral triangle with the 4th-magnitude stars Beta and Delta^2 Chamaeleontis. IC 2631 stands out most clearly when you look to the side of the nebula instead of directly at it, a technique known as averted vision.

If you extend a line between Acrux and Beta Cha another two-thirds of its length, you'll arrive at our final destination: the South Celestial Pole. On March evenings, the so-called Pole Star — 5th-magnitude Sigma (σ) Octantis — stands 1° to the pole's lower right. Although it's faint and lies in one of the sky's more barren regions, Sigma is known to many Northern Hemisphere observers even though most of them have never seen it.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
10 P.M. March 1
9 P.M. March 15
8 P.M. March 31

Planets are shown at midmonth

MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

MARCH 2015

Calendar of events

3 The Moon passes 5° south of Jupiter, 8h UT

4 Venus passes 0.1° north of Uranus, 20h UT

5 The Moon is at apogee (406,385 kilometers from Earth), 7h33m UT

Full Moon occurs at 18h05m UT

6 Asteroid Iris is at opposition, 13h UT

9 Asteroid Juno is stationary, 15h UT

11 Mars passes 0.3° north of Uranus, 20h UT

12 The Moon passes 2° north of Saturn, 8h UT

13 Last Quarter Moon occurs at 17h48m UT

14 Saturn is stationary, 22h UT

19 The Moon passes 4° north of Neptune, 2h UT

The Moon passes 5° north of Mercury, 5h UT

The Moon is at perigee (357,584 kilometers from Earth), 19h38m UT

20 New Moon occurs at 9h36m UT

March equinox occurs at 22h45m UT

21 The Moon passes 0.1° north of Uranus, 11h UT

The Moon passes 1.0° south of Mars, 22h UT

22 Asteroid Nysa is at opposition, 16h UT

The Moon passes 3° south of Venus, 20h UT

25 The Moon passes 0.9° north of Aldebaran, 7h UT

27 First Quarter Moon occurs at 7h43m UT

30 The Moon passes 6° south of Jupiter, 10h UT